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BIOLOGICAL IMPACT CAUSED BY CHANGES ON A TROPICAL REEF

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Introduction of the effluent is shown to be responsible for recent destruction of reef margin corals. Effluent is found to stratify beyond the surf zone and is no longer a threat to benthic organisms.

Coral transect studies show an increase in recent coral re-colonization on the reef front, terrace and slope since the Acanthaster infestation. No such recovery is evident in benthic habitats of the reef margin, exposed to effluent.

Thermal simulation experiments, performed on a series of reef corals in the laboratory, suggest mean upper tolerance limits for the corals between 30 and 33°C. These temperatures are common on the reef margin adjacent to the power plant. Sublethal elevation of temperature is shown to reduce growth rate in some of the coral species.

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ABSTRACT

A biological study is conducted on a fringing coral reef adjacent to a thermoelectric power plant on Guam, before and after release of plant effluent. The before study shows corals of the reef front, submarine terrace, and seaward slope to be devastated because of a recent infestation by the crown-of-thorns starfish, *Acanthaster planci* (L.). The reef margin is found to comprise a rich and diverse coral reef community, presumably spared from *Acanthaster* attack by strong wave surge. The reef flat is naturally depauperate due to frequent exposure at low tide.

Release of plant effluent results in an elevation of water temperature on the adjacent reef flat and reef margin, and wave action exposes even the deeper parts of the reef margin to temperatures above ambient as well as other potentially detrimental effluent parameters such as chlorine and heavy metals. Introduction of the effluent is shown to be responsible for recent destruction of reef margin corals. Effluent is found to stratify beyond the surf zone and is no longer a threat to benthic organisms.

Coral transect studies show an increase in recent coral re-colonization on the reef front, terrace and slope since the *Acanthaster* infestation. No such recovery is evident in benthic habitats of the reef margin, exposed to effluent.

Thermal simulation experiments, performed on a series of reef corals in the laboratory, suggest mean upper tolerance limits for the corals between 30 and 33°C. These temperatures are common on the reef margin adjacent to the power plant. Sublethal elevation of temperature is shown to reduce growth rate in some of the coral species.

Recommendations are made to release the effluent in deeper water in order to provide a greater mixing zone and to relieve present stress on reef margin organisms.

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SECTION I

CONCLUSIONS

GENERAL BIOLOGICAL CONDITIONS OF THE TANGUISSON STUDY AREA PRIOR TO RELEASE OF PLANT EFFLUENT

The first two generating units of the Tanguisson Power Plant are located on an elevated terrace covered with bioclastic material. The plant site is on an old coconut plantation. Attempts were made by the contractor to save most of these trees, but a considerable portion of the previous well-developed strand vegetation was removed well outside the immediate construction site to provide a mobilization area. On the landward side of the plant is a steep limestone cliff with a talus slope at its base. The cliff is about 100 m high and has a good growth of limestone forest vegetation on its sides and slopes. This vegetation has been left basically undisturbed except where power transmission lines and a pipeline pass up the cliff.

Seaward of the power plant is the first of the series of reef zones studied. The intertidal is the first zone encountered and, in the immediate vicinity of the plant, consists of the remnants of an elevated fossil reef. There are sand beaches along the intertidal to the north and south of the plant.

The reef zone seaward of the intertidal is the reef flat. This is a limestone platform that is mostly flat and pavement-like except for a few scattered holes and channels. The reef flat has a characteristic biota that is mostly dominated by fishes, crustaceans, echinoderms, and benthic algae. Corals are rare on the reef flat and in general, it is a biologically depauperate area due to frequent exposure of much of its surface at low tide. Temperatures on the reef flat are often 2 to 3°C higher than oceanic temperatures when low tides occur in midafternoon.

The next zone is the reef margin and is that portion of the reef where waves break against the reef platform. The area is dissected by numerous surge channels and is the site of a rich and diverse coral fauna. Unlike the remaining zones, this one has not been subjected to intense predation by the coral-feeding starfish, Acanthaster planci (L.).

We suspect that heavy wave attack in this area prevents the animal from attaching to corals in order to feed. Temperatures in this zone and those that follow had a range of between 26 and 29°C, a mean annual temperature of 27.6°C, and an annual fluctuation of only about 3°C.

The reef front is the next zone and in most respects closely resembles the reef margin. The primary exception is that it is a deeper, more steeply sloping zone and not subjected to breaking waves. The lower portion of this zone has been completely devastated by Acanthaster.

At the 6 m contour, the reef front flattens out and grades into the first submarine terrace. This area was, until recently, covered by a rich coral community but has now been wiped out by Acanthaster. Nearly 100 percent of the former coral community was destroyed.

At about 15 m, the submarine terrace ends and the bottom slopes steeply down to the next submarine terrace at about 32 m. This drop-off is known as the seaward slope and, as in the case of the first submarine terrace, once supported a luxuriant growth of reef corals. Again the area was found to be devastated by the starfish.

The second submarine terrace is basically a flattened shelf covered with sand derived from the nearby seaward slope. Some scattered coral knolls are found here but these too are now mostly devoid of live corals.

THE EFFLUENT AND ITS DISTRIBUTION

Circulating water is pumped through the power plant for once through condenser cooling. The source of this water is the Philippine Sea. Each generating unit uses about 17,000 gpm with one pump on the line, and about 28,000 with two. (One pump per unit is now being used almost exclusively since the time the original manuscript was prepared, personal commucation with P. E. Cavote.)

At least four things happen to cooling waters and entrained planktonic organisms as they pass through the plant.

1. Physical agitation at the circulating pumps.
2. Leaching of heavy metal ions, particularly copper, from the piping.
3. Addition of chlorine to control sliming.
   (Chlorination has been stopped completely since the preparation

of the original manuscript, personal communication with P. E. Cavote.)

4. Elevation of temperature.

The outfall site for this effluent is at the intertidal zone. Water enters a stilling well and rises up to the level of the reef flat. Effluent then flows seaward, directly across the reef flat, in a relatively narrow band (10 to 15 m wide). At the reef margin, the effluent encounters breaking waves and is mixed with incoming seawater. This mixing effectively carries effluent to the bottom of the surge channels. The mixing water tends to be carried parallel to the reef margin and front in a series of zig-zag patterns. The lateral movement is due to prevailing offshore currents, and the zig-zag to wave action. Currents may either run northeast or southwest at Tanguisson. When the effluent is carried to the north, it immediately encounters a rip current that emerges from the intake channel surface. The rip diverts the effluent seaward out over the terrace and away from the reef margin and front. When the plume is carried to the southwest a considerable portion of the reef margin and front is washed by effluent. The effluent gradually shifts seaward as it moves south toward Transect C. A second rip current occurs in surge channels near Transect C that serves to divert the remainder of the effluent seaward.

Once the effluent reaches the submarine terrace, it comes under the influence of the offshore water mass. Except for wave transport during times of heavy seas, effluent entering this water mass is carried either northeast or southwest and away from the study area. Its direction depends upon tide and local climatic and related oceanographic conditions. Effluent moving northerly was not tracked beyond Tanguisson Point. Effluent moving south is usually deflected seaward off of Amantes Point and moves in a westerly direction away from the island. This may be due to a weak convergence zone that would be expected to form opposite the Amantes headland. A recent drift cross study showed a drift that rounded Amantes Point and continued south opposite Tumon Bay. The drift crosses ultimately swung seaward as they approached Ypao Point. Except in the areas immediately adjacent to the plant, we expect all effluent to be carried gradually seaward primarily because of the influence of the prevailing east and northeasterly winds on the surface water.

GENERAL BIOLOGICAL IMPACT OF THE EFFLUENT AND PLANT CONSTRUCTION

As the effluent passes clear of the mixing action of the surf zone, thermal stratification occurs. The heated portion of the effluent is confined to the upper 1 to 2 m of the water mass and is no longer a threat to the benthic biota and most of the other organisms in the water column.

Concern for potential environmental damage is, therefore, limited to the reef flat and reef margin opposite the plant and usually between Transects A and C. All other zones were found to be outside the vertical and horizontal limits of the effluent plume.

On the reef flat we found that the few scattered corals that occurred prior to plant operation died in the effluent plume. Fishes that are characteristic of the reef flat (many are territorial species) abandoned the plume area. The same was true for crustaceans and echinoderms. Benthic algae normally present in this area, for the most part, disappeared and was replaced by a predominately blue green algae community. This implies that, with regard to the algal community, the area has reverted to an early stage of ecological succession that features the pioneering blue greens. The reef flat is not considered particularly rich in terms of diversity or biomass, and the area affected is confined to the immediate area of the effluent plume. A "normal" reef flat community is found immediately adjacent to the plume.

The most striking effect on the reef that we can attribute to plant effluent, is on the reef margin. A massive die-off of the reef coral community has occurred here. There is a central core of about 10,300 m^2 spread along along a linear front of about 400 m, where most of the corals have been killed. A peripheral zone lies outside of this area that shows dead, dying, and bleached corals (corals that have extruded their pigmented symbionts). This zone has shown a constant and gradual die off. The coral kill began in December, 1971, when the plant (Unit No. 1) began full scale operation and is still going on today in the peripheral zones after addition of Unit No. 2 in May, 1973. The total area affected to date is 20,000 m^2 and spreads along 600 m of the reef margin.

The obvious question at this point is, what factor or factors in the effluent are affecting the corals? The first factor mentioned above, agitation, would not be involved with the coral kill but might affect entrained planktonic organisms through mechanical damage. This was not a part of the study and was not pursued except for one significant phenomenon. In this case large numbers of the juvenile rabbitfish, Siganus spinus, were entrained by the circulating water and killed, possibly by mechanical damage from the pumps. We suspect that many thousands of these animals are killed when they make their seasonal migrations from the pelagic to the inshore environment. Enormous numbers of the juveniles are found in the intake channels of both the Tanguisson and Piti power plants during their migrations in April, May, June, and October.

Copper is known to be toxic to marine organisms. Total copper values in the outfall were at times nearly three times (2.9 ug/l) higher than the values in the intake channel (1.0 ug/l), and nearly 30 times higher than control samples taken one half mile to sea (0.1 ug/l). The values were quite variable and are still below those reported as normal in oceanic water (about 3 to 10 ug/l total copper). We are uncertain at this point as to what role copper might play in the death of the corals. We are, however, of the opinion that the effect is minimal at this time. This factor could be multiplied as the plant ages.

Chlorine is another toxic material that might have caused the death of some of the first reef corals that were effected. There are no bioassay data available as to the level of chlorine that is toxic to coral species and we had no way of measuring either free or residual chlorine during the project. We did note on one occasion, when the power plant ran out of chlorine from November 2 to November 20, 1972, that reef flat fish species began recolonizing the reef flat and the stilling well. These species seemed unaffected by the turbulence of effluent or the heat. However, when chlorination was started again, the species disappeared immediately. Subsequent investigations by Guam Power Authority has shown that biological fouling of the condenser tubes is minimal and chlorination has ceased altogether.

Waste heat in the effluent is considered to be a very likely source of most, if not all, of the coral damage. We found a mean delta T of 7.0°C during the first 28 months of plant operation. The range of intake temperature was 26.5 to 29.5 and mean was 27.7°C. Outfall temperature ranges were 32.5 to 37.0 with a mean of 34.7°C. Sampling showed that, except during higher high water tides and heavy seas, there is little reduction in temperature from the stilling well to the reef margin. Wave attack immediately begins to mix the water, and the temperature drops as mixing proceeds. Seawater temperatures fluctuate between 29 and 35°C along the reef margin adjacent to the plant. Data on the elevation of temperatures at the reef margin are incomplete due to the inaccessability of this wave washed zone. We found that we were unable to work in the area except during rare periods of extreme calm. At these times the effluent was stratified and we were not able to measure its effect below about 1 m. Attempts to place in situ temperature recording instruments in this zone usually resulted in damage to the instruments.

In addition to effluent damage, there was some initial physical damage to the reef from construction activities. A channel was excavated from the reef margin and reef flat zones to provide access for cooling water to plant condensers. The rich coral community at the immediate entrance to the intake channel was obliterated by dynamiting and excavation. This constitutes an area of only about 250 m^2. There was little damage done to the reef margin corals either to the left or right of this channel. The remainder of the channel has physically replaced about 1835 m^2 of reef flat environment. In terms of biomass and diversity, the loss is probably less than the smaller area disturbed along the reef margin.

THERMAL SIMULATION EXPERIMENTS WITH REEF CORALS

It was certain that plant effluent had caused a massive coral kill along the reef front, but it was not so obvious as to what plume parameter or parameters might be involved. Synergistic effects or other factors which we are as yet unaware of might be responsible for some of the damage.

A laboratory experiment was designed to eliminate all the potential power plant stress parameters on reef corals except temperature. The system was set up at the Marine Laboratory and used fresh, uncontaminated seawater from the reef margin at Pago Bay. Reef corals were subjected to temperature elevations of +2, +4, and +6°C above summer ambient (28.5°C). The experimental tanks were heated with immersion heaters and had electronic control devices. This, in effect, simulate the thermal influence of plant effluent while eliminating the other parameters.

Eighteen species of reef corals have been tested in the thermal simulator thus far. There was no significant difference in survival between most coral species in the ambient control tanks and those at +2°C above summer ambient. At +4°C above ambient, most of the corals were usually dead within 6 to 14 days. The coralla went through the same stages of death as those at Tanguisson Point. The symbionts were expelled first, leaving the coral polyps bleached white. This stage was usually reached within a few days and was followed by death within the period described above. Coral species in the +6 tanks were usually all dead within six days or less. It would appear that the mean upper thermal tolerance limit for the majority of the species is between 30 and 33°C. These temperatures are not uncommon at the reef margin near the plant. The apparent slow die off of the corals may be correlated with the mixing of plant effluent with oceanic water. Corals would not receive constant exposure in the peripheral zone of the coral kill due to variability of wave attack in direction and magnitude, tide cycle, and current direction. Corals tested at sublethal temperature elevations showed a general reduction in growth when compared with controls.

Effects of thermal stress on other marine organisms are considered in separate reports in Appendices A to D.

SUMMARY

We feel that there is no doubt that effluent from the Tanguisson Power Plant is responsible for the death of the corals along the reef margin as well as their continued dying. Laboratory data indicate that elevated temperature is the primary but not necessarily the only causal factor.

Evidence gathered from the Acanthaster killed reef front, submarine terrace, and seaward slope zones indicates that corals are now resettling and recolonizing these areas. There is no evidence of coral resettlement in the reef margin area within the influence of effluent. Furthermore, it is apparent that the coralline algae are also being killed by the effluent (Appendix D). These organisms normally cover corals killed by Acanthaster and result in a stabilization of the reef structure that prevents erosion. There is the possibility that the absence of both calcium carbonate secreting corals and coralline algae will result in biogeochemical and physical erosion of the reef platform opposite the power plant.

SECTION II

RECOMMENDATIONS

Jokiel and Coles (unpublished manuscript) recently completed a study of the Kahe Point power generating facilities in Hawaii. Their results are similar to ours and we feel that they summed up the problem quite well.

> "The use of the marine environment for the disposal of waste heat is an attractive concept in a land-scarce island community. Cooling tower and cooling pond schemes are expensive in terms of terrestrial space. The Pacific Ocean represents a heat sink of incomprehensible proportion. The major problem in using the ocean as a receiving body for the heat lies in getting the waste heat far enough away from the shoreline so that shallow inshore marine communities are not disrupted. Intial dilution with the receiving water mass must be high so as to avoid excessive temperature increases over ambient conditions."

We are in agreement with the logic expressed above and would recommend the following:

1. Abandon the present outfall structure.
2. Build a new outfall line from the plant to the edge of the submarine slope (a distance of about 250 m and depth of about 10 m).
3. Place a diffuser structure at the end of the line.
4. Use the existing intake channel for the pipe run through the reef flat and reef margin, thus eliminating the need for additional channeling. If channeling is necessary on the submarine terrace, now is the time to do it. Coral recovery following Acanthaster damage is at an early stage and would not be significantly affected if construction is completed soon.

The above action would result in relief of stress on the damaged reef margin zone and we suspect that corals and coralline algae would recolonize the area. Effluent released offshore would rise rapidly to the surface due to the low density of hot water. This would provide a 10 m deep mixing zone and the resultant surface plume would be stratified and well clear of the benthic reef biota.

SECTION III

INTRODUCTION

BACKGROUND

The island of Guam lies at the southern end of the Mariana chain. This far-flung territory of the United States is experiencing the pressures of boomtown growth. Both civilian and military components are contributing to this phenomenon. The island population in 1960 was 67,000 -- it now stands at nearly 100,000 and the rate of growth shows no sign of decreasing in the near future. There has been a frantic expansion of construction activities on the island to create more homes for the growing population and to provide more industrial, business, military, and tourist facilities which support the expanding economy.

The explosive growth of so many power-consuming entities has, predictably, caught the island woefully short of power-generating facilities. This has led to short term and often shortsighted planning for new generating plants. The net result is that locations for these new facilities are frequently chosen for convenience of the power industry and with little regard for the environment.

In order to meet the expanding power needs of Guam, plans were made to construct generating facilities at Tanguisson Point (Fig. 1). A series of four units were to be constructed on an incremental basis over a period of years to try to keep abreast of the growing power curve. Unit No. 1 was scheduled for completion in early summer 1971 but did not become operational until December 1971. (Two units were operational by May 1973.)

Each unit was to have a generating capacity of about 26 megawatts. The units were to be oil-fired, steam electric facilities, utilizing sea water for condenser cooling. Cooling water for all units was to be taken from the adjacent waters of the Philippine Sea through an intake channel, 14 m wide and 2 m below mean low water, cut through the reef margin and reef flat. Plans for Unit No. 1 called for two circulating pumps with capacities of about 17,000 gpm each, to carry water to the condensers.

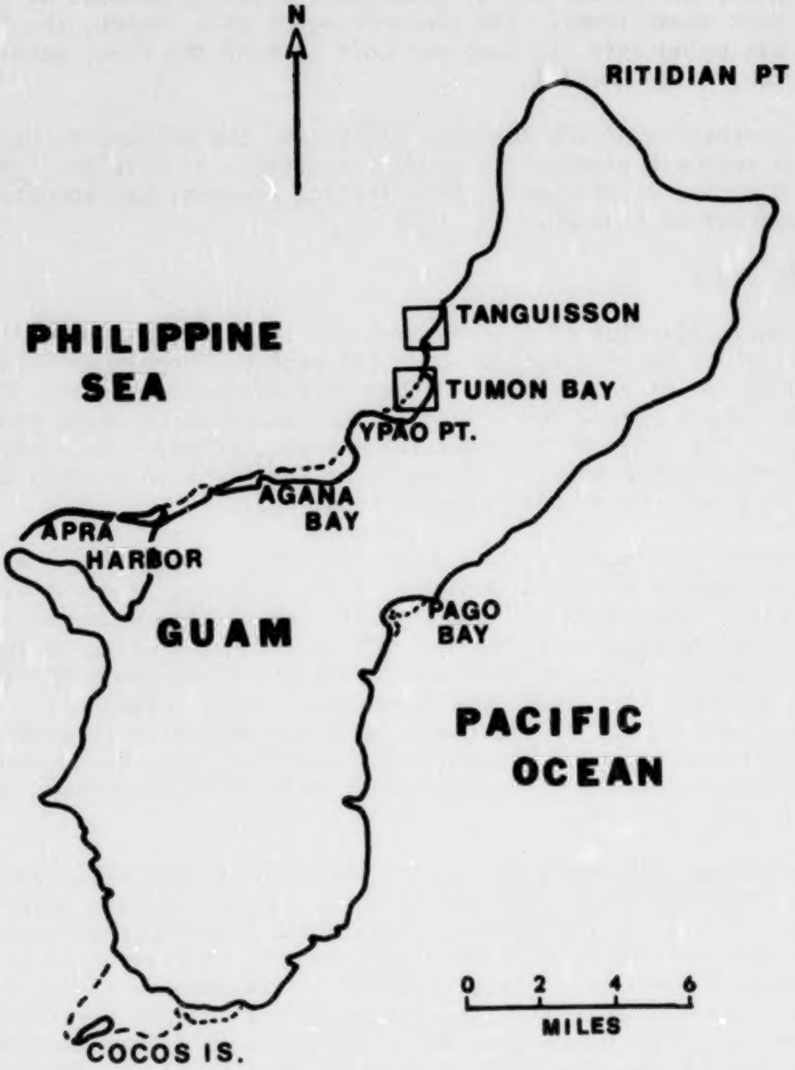
N
RITIDIAN PT
PHILIPPINE SEA
TANGUISSON
TUMON BAY
YPAO PT.
AGANA BAY
APRA HARBOR
GUAM
PAGO BAY
PACIFIC OCEAN
0 2 4 6
MILES
COCOS IS.

Figure 1 Location map of Guam showing study areas

Heated effluent was to be released in a stilling well at the intertidal. With one pump on the line a delta T of 12-14°F was predicted and with two (about 28,000 gpm) 9-11°F (personal communication, Frank Melder). Operational plans called for use of both pumps about 50 percent of the time during peak power times. (At the writing of this report, the Tanguisson system was using only one pump per unit most of the time, personal communication, P. E. Cavote).

At the suggestion of EPA Regional officials, the University of Guam submitted a research proposal to study the effects of Unit No. 1 on the adjacent marine environment. This initial proposal was accepted and the grant awarded on September 13, 1969.

SCOPE OF STUDY

The primary objective of the research was to evaluate (Phase I) the biological condition of a section of coral reef at Tanguisson Point prior to the completion of Unit No. 1 and then to reevaluate the reef (Phase II) after the plant became operational. The second phase would provide a catalog of the induced environmental changes, if any. This objective was deemed valuable because it was to be the first such study of thermal impact on a well-developed fringing coral reef.

As a secondary objective, the survey included a study of the effect of the coral feeding crown-of-thorns starfish, Acanthaster planci (L.), which had recently invaded Guam. The significance of this study was twofold. First it was necessary to document (Phase I) any existing damage attributed to the starfish and thus avoid possible confusion with effects of thermal effluent that might be "discovered" later (Phase II). Second, existing starfish damage provided a unique opportunity to study reef recovery following severe damage. The starfish, in a sense, simulated an environmental catastrophe that might have occurred through some form of pollution.

By a fortuitous circumstance, one of the authors (Randall) had been studying the distribution of reef corals prior to the starfish infestation in Guam. This study was concentrated on the fringing reef opposite Tumon Bay, an area contiguous with the Tanguisson Point study area (Fig. 1). These valuable collections and transect information form a cornerstone for this report because they provide us with a control area comparable with the Tanguisson study area and allow us to make some reasonable approximations of what the Tanguisson reef was like in an undisturbed condition.

Near the end of Phase I, the first of our two continuation proposals was submitted to begin Phase II. The continuation proposal was accepted, however, in addition to the original Phase II objectives, the Agency asked that heavy metals be monitored and that thermal stress experiments be done in the laboratory. These additional objectives were added without increase to the project budget. The net result of the additional work load and cost was deemphasis of some of the original proposal objectives and increased emphasis on the coral succession work and the new thermal simulation experiments.

The availability of the necessary equipment for thermal simulation allowed for some additional work on other organisms. This work was done by several of our colleagues at the laboratory and the resultant papers are found in Appendicies A-D. One such paper investigates the effect of elevated temperature on the metabolism of *Acanthaster planci*. This work was done by Dr. Masashi Yamaguchi and is found in Appendix A. Graduate student John Rupp was a valuable research assistant during our work and at the same time concluded a Master's thesis on the effects of elevated temperature on the embryology of several tropical echinoderms (Appendix B). The third contribution, by graduate student Tom Hohman and Dr. Roy T. Tsuda, is a preliminary study dealing with the effect of temperature on photosynthesis and respiration in the green alga, *Caulerpa racemosa* (Appendix C). Graduate student Greg Gordon was provided with grant support for a preliminary study of the effects of heated effluent on two species of coralline algae. This study was submitted as a student report (Appendix D).

The data added by our colleagues is above and beyond the objectives of our grant proposal and we are indebted to them for the additional results regarding the effects of thermal effluent on tropical organisms.

SECTION IV

THE STUDY AREA

GENERAL DESCRIPTION OF GUAM

Guam is the largest and most southerly of the fifteen small islands that make up the Mariana group in the western Pacific Ocean. It is 48.3 kilometers in length, and ranges in width from 6.5 kilometers at the narrow central waist to 18.5 kilometers at its widest part. The island has a land area of 549 square kilometers.

The northern half of Guam, that includes the study area, is a limestone plateau bordered on the coasts by steep cliffs that range in elevation from more than 180 m at the north end to less than 60 m at the centrally located, narrow waist. The limestone is porous and no streams are found on the northern plateau. The western and northern coasts are bordered by fringing reefs.

CLIMATE

The following summary of climate and rainfall data is condensed from a report found in Tracey et al[1]. Guam has a warm, humid climate that is mainly determined by its oceanographic setting. The island lies within the belt of westward-moving, warm humid air of the tropics, which is produced between the subtropical anticyclones of the northern and southern hemispheres. Variations in the weather are caused by cyclonic eddies or whorls that form continuously, sweep westward, and dissipate. These disturbances may grow in size to become tropical storms or typhoons. The period from July to November includes the rainy months, January to May is considered the dry season, and June and December are transitional months. The mean annual rainfall on Guam ranges from less than 228.6 cm in the lee of the mountains to more than 279.4 cm in the higher mountain areas. About two thirds of the annual rainfall occurs during the rainy season. Tradewinds predominate during the dry season. Winds usually become light and variable during the wet season, except during storm conditions.

PHYSIOGRAPHIC DESCRIPTIONS

General Comments

The northern limestone plateau, which borders the study area, is very porous, resulting in a well-developed Ghyben-Herzberg fresh water lens system. Water escapes continually along most sections of the intertidal zone. This fresh water seepage onto the reef flat is particularly noticeable along sandy beaches at low tide, where it forms small rills. Emery[2] measured the fresh water seepage along a 47 m section of Gogna Beach at Tumon Bay and found it to be 42.5 liters per second. Analysis of beach samples from Tanguisson Point by Emery[2] shows that the sediments of this region are nearly 100 percent bioclastic. This is due to the absence of rivers and streams emptying onto the reef flats of the study areas.

The Tanguisson Power Plant is located on an elevated terrace that is covered with beach deposits (Fig. 2). Vegetation around the plant is composed of an old coconut plantation and a well-developed strand vegetation along the beaches. This terrace is backed by steep limestone slopes and a cliff on the landward side. The cliff reaches heights of about 100 m. Both the slopes and cliff support dense limestone forest vegetation. To the south, the terrace narrows down and eventually disappears near Amantes Point (Fig. 3). To the north, the terrace includes the Naval Communications Station (NCS) swimming beach and then continues along the coast up to Tanguisson Point where it narrows to a thin strip. Immediately to the west is the first of the reef zones described below.

The reef platform and slopes are divided into several reef divisions after Tracey et al[1]. These divisions are based on various physical parameters such as degree of reef surface exposure at high tides, degree of reef surface submergence at low tides, amount of reef slope, and reef growth and erosional structures.

The biologic parameters have been deliberately omitted from the fringing reef descriptions. This was done because later parts of this report (Section X) describe reef coral distribution by zones in detail, and because future workers investigating reef recovery would experience difficulty in comparing structures and descriptions of former living coral reefs with those that have since been killed by *Acanthaster planci*.

A series of transects were established and are shown on Figure 3. Reef profile and zones for the Tanguisson study area are shown on Figure 4.

Tanguisson Point Fringing Reef

Tanguisson Point study area (Figs. 1-3) is located between Amantes Point and Tanguisson Point. The fringing reef platform along this section of coastline is relatively narrow. It ranges in width from 70 m at Transect

Figure 2 Aerial photograph of the Tanguisson Power Plant site

A to 110 m at Transect C. The fringing reef has a westerly exposure to the sea.

Intertidal -- This zone is the portion of the beach or shore covered by water at high tide and exposed at low tide. The intertidal zone bordering the transect locations at Tanguisson Point is composed of bare limestone, with the exception of a sandy section at Naval Communication Station (NCS) swimming beach, and several other small sandy sections between Transects B and C (Figs. 2-3). At Transect B this zone is 40 m wide and consists of limestone ridges, knobs, and pinnacles, separated by numerous interconnecting channels (Fig. 2). These channels are relatively flat-floored and about the same general level as the reef flat. The upper half of the emergent structures is exposed during high tide and deeply solution-pitted. Relief of these structures ranges from about a meter at the shoreward side to 20 cm on the seaward side. Unconsolidated sediments are scarce along the bare rocky regions, except for local patches of course gravel and boulders. Sediments at the two beach areas are mostly sand, largely composed of worn foraminiferan tests. At low tide fresh water can be seen escaping from the intertidal zone and at sandy locations it forms small rills similar to those described by Emery[2] at Gognga Beach.

Reef Flat -- This is the flat limestone platform that extends from the intertidal zone to the wave-washed reef margin (Figs. 2-4). The outer seaward part of the reef flat is slightly elevated in respect to the inner shoreward section and, at low tide, is often exposed while the inner part retains water. On this basis, the reef flat is divided into two subzones--an outer reef flat subzone that is exposed during low tide, and an inner reef flat subzone that is covered by water at low tide. The inner water mass is here called the "moat".

The inner reef flat subzone at Tanguisson Point, is poorly developed at Transects A and C and is absent altogether at Transect B. During low tide at Transects A and C, a few shallow, irregular-shaped pools and a depressed zone north of Transect C retain water and constitute the moat of the inner reef flat. The floors of these pools contain coarse gravel, boulders, and scattered emergent limestone patches. At NCS Beach, water is retained at low tide, but this is partly due to dredging and blasting and does not represent natural conditions.

The outer reef flat subzone is more extensive than the inner reef flat and represents most of the reef platform. At Transect B, where no inner reef flat occurs, the outer reef flat extends from the reef margin to the intertidal zones and is 60 m wide. At Transects A and C, the subzone width is 50 m and 90 m respectively. At low tide, the exposed platform is a flat pavement with very little relief. A few small shallow pools (10 to 50 cm deep) are widely scattered over the surface. Sediments are scarce and accumulate only in the small pools. An algal turf covers most of the surface and contains many foraminifers.

Reef Margin -- This zone is represented by that part of the seaward edge of the reef flat platform that is constantly awash even at low tide (Figs. 2-4). The reef margin at Tanguisson Point is slightly elevated, about 20 cm above the outer reef flat level, and forms a low, poorly-developed algal ridge. The algal ridge development is greatest at Transect B. Observations immediately seaward of Transect B show that the degree of reef front slope is less than at Transects A or C, causing greater surf action and thereby enhancing algal ridge development. The reef margin width is fairly uniform and, at the transect locations, ranges from 20 to 30 m. The seaward edge is very irregular and is cut at right angles by short surge channels 1 to 3 m wide, 2 to 4 m deep, and up to 20 m in length. Some surge channels coalesce and fuse at their upper margin, forming cavernous channels beneath the reef margin platform. Most of the cavernous channels open at intervals along the fusion zone, forming pools and open cracks. In cross section, most surge channels are wider at the bottom than at the upper margin, which may be due partly to growth at the upper regions and abrasion at the base or floor which contains large, rounded boulders. Most boulders, however, do not show evidence of constant movement because most are encrusted with red algae and small coral growths. These boulders are probably moved about only during typhoons and other storms. Surge channels are separated by lobate elevations called buttresses that slope seaward toward the reef front zone. The upper surface of a buttress is very irregular, with knobs, pinnacles, and in many places is honeycombed with numerous interconnecting holes.

Reef Front -- The reef front represents the extreme seaward edge of the reef flat platform, where the reef margin abruptly increases in depth and degree of slope (Fig. 4). This zone is constantly covered with water. The reef front is composed of the seaward sloping extensions of the reef margin buttresses and surge channels. The point where the submarine buttresses and channels terminate marks the seaward boundary of the reef front. Generally, the 6 m submarine contour coincides with the seaward limit of the reef front. Width of the reef front zone is variable and ranges from 70 m at Transect A to 60 m at Transect C. Submarine channels near the reef margin are 2 to 6 m in depth and commonly branch into several secondary channels. These channels are similar in cross section to those described above. Some submarine channels widen into holes 5 to 15 m in diameter, with large boulders covering their floors. Submarine buttresses slope seaward at 10° to 15° and are extremely irregular on the upper surface due to the presence of coral-algal knobs, bosses, and pinnacles. At the seaward half of this zone, these various prominences may have a relief of as great as 2 to 3 m.

Submarine Terrace -- The first submarine terrace represents a noticeably flattened region when compared to the reef front and seaward slope zones (Fig. 4). This zone ranges in width from 40 m at Transect C, to 110 m at Transect B. The shoreward margin of this zone begins at the 6 meter

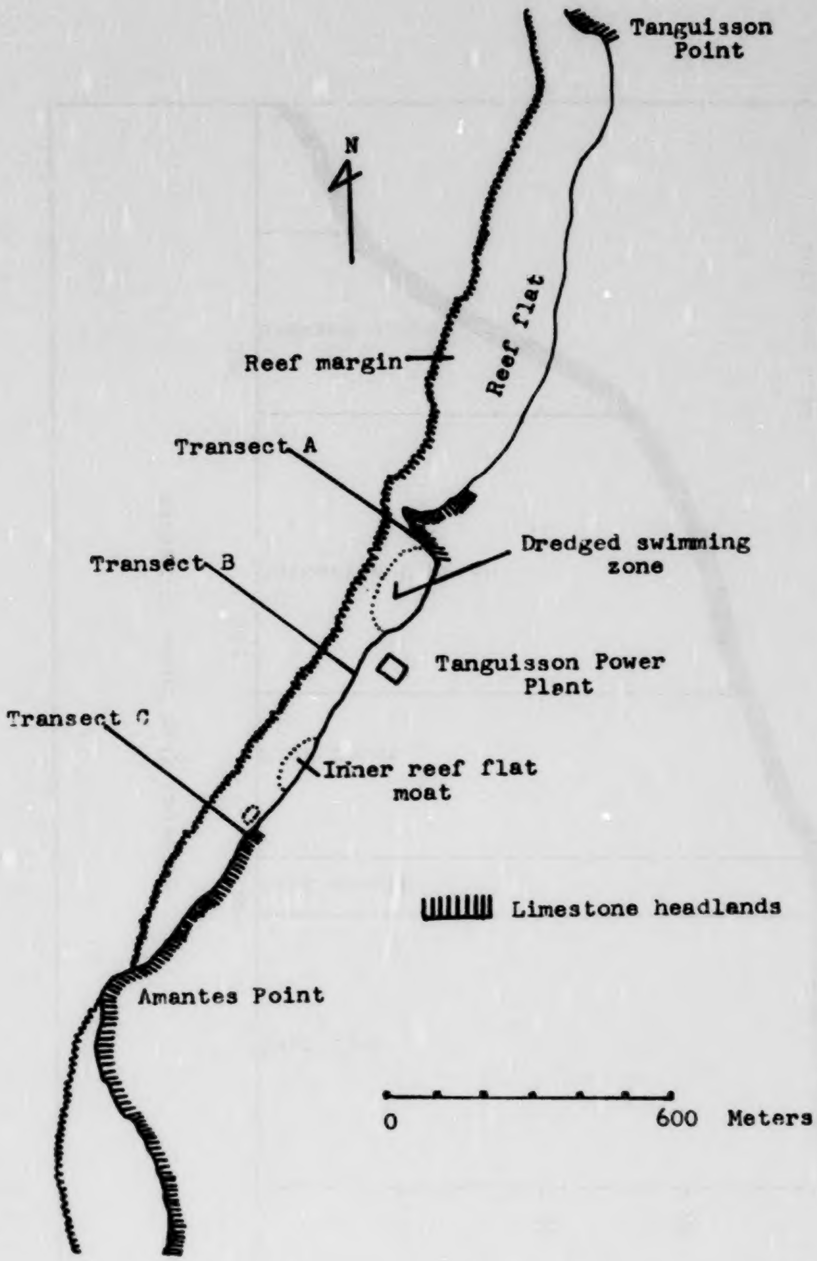
Tanguisson Point
N
Reef flat
Reef margin
Transect A
Transect B
Dredged swimming zone
Tanguisson Power Plant
Transect C
Inner reef flat moat
Limestone headlands
Amantes Point
0
600 Meters

Figure 3 Detailed map of the Tanguisson Point study area showing transect locations

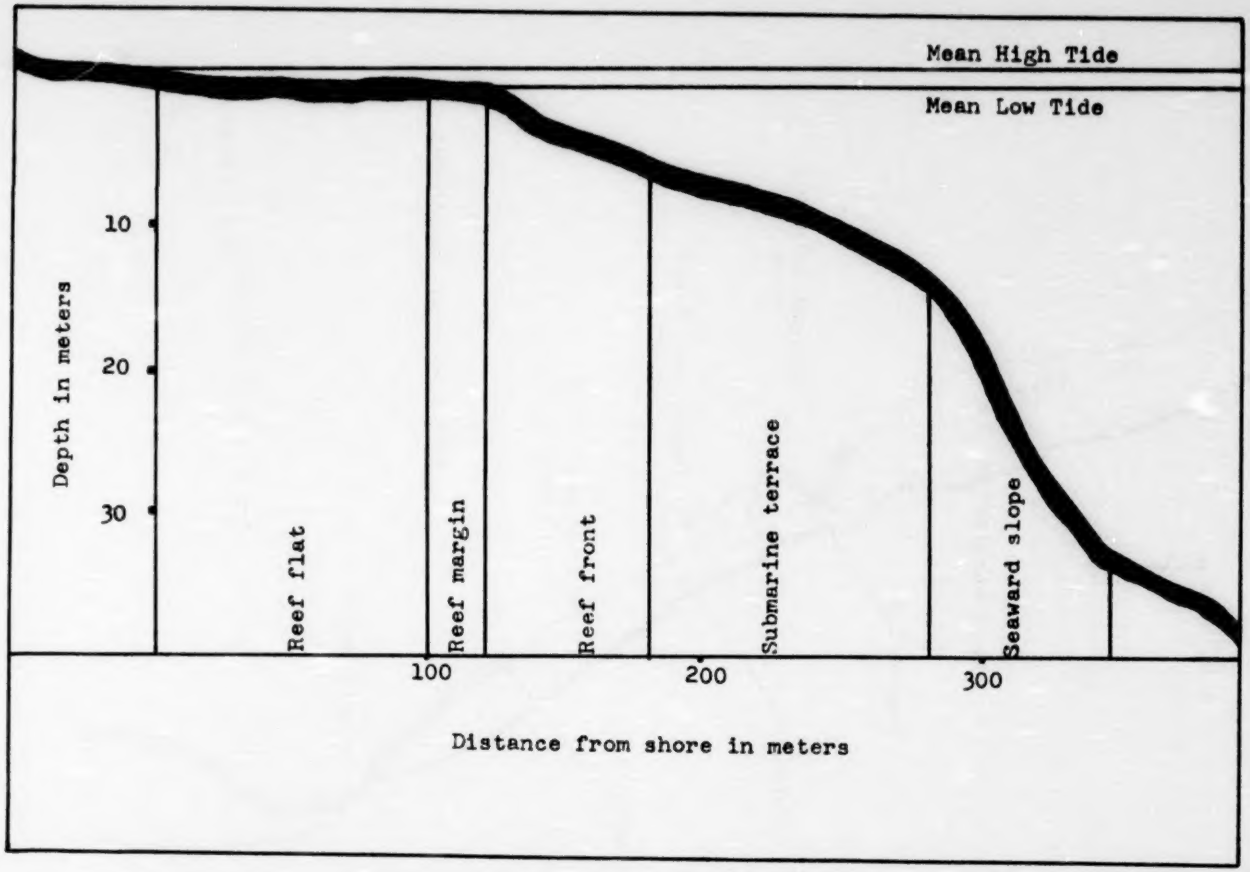

Figure 4 Reef profile at Transect B

contour but its seaward margin, where the steep seaward slope begins, is located at the 10 to 15 m contour. Relief of the surface features ranges from 1 to 2 m. Occasional coral mounds or pinnacles attain a relief of 3 m. Shallow channels up to a meter in width and depth cut across the surface at some locations. Sediments are found in localized patches in holes, cracks, and in shallow channels. These sediments consist mostly of rounded boulders, coarse sand, and gravel.

Seaward Slope -- At the seaward edge of the Tanguisson Point submarine terrace, the degree of slope abruptly increases and sharply differentiates the seaward slope from the terrace. Width of this zone at the three transect locations averages 70 m. The steep seaward slope flattens into a second submarine terrace at about the 30 to 35 m depth. This second terrace probably corresponds to the 32 m submarine terrace found by Emery[2] at Tumon Bay.

Distinct linear sediment tracks can be traced from the upper part of the slope to the second submarine terrace below. Although depth of sediments was not measured at the second terrace, visual observations made with SCUBA indicate a considerable accumulation at the base of the slope.

A conspicuous feature of the second submarine terrace is the presence of scattered coral knolls. These knolls arise from the sandy terrace floor at a 40 to 45 m depth and have a relief of up to 10 m.

SECTION V

CURRENT PATTERNS

GENERAL COMMENT

Transport of water masses around the island of Guam is similar to that for most islands in the Central Pacific (i.e. Avery et al[3]). The prevalent northeast tradewinds of the area play a major role in generating the enormous North Equatorial Current that sweeps by the island from east to west. This great current is responsible for much of the energy that transports water along the coasts. According to Emery[2] the north equatorial current splits on the northeast corner of the island and streams around the south end of Cocos Island and around the north at Ritidian Point (Fig. 1). These two streams then sweep along the west coast where they supposedly rejoin west of Apra Harbor. As they move along the western coast, the near shore portions of the streams are distorted and forced into complicated eddy systems by prominant headlands and local submarine topography. These currents may also alter their flow because of seasonal changes in strength and direction of the North Equatorial Current. They are further complicated in some areas by tidal currents superimposed on them, often resulting in a temporary reversal of direction with changes in tide (Jones and Randall[4]).

Inshore water movement is generated primarily by tide changes and wave action. These two forces combine to transport water over the reef margin onto fringing reef platforms around the island. This water often forms long shore currents on reef flats for some distance and then returns to sea as rip currents via natural low spots and surge channels through the reef margin.

It was apparent at the beginning of this study that the Tanguisson water mass could be divided into three parts. First there is the shallow water portion bathing the reef flat and a portion of the reef margin. Second, there is that portion which encompasses the reef front and remainder of the reef margin. The third component includes the submarine terrace and seaward slope. Overlap of the first two parts may occur because of surge activity in the shoaling water that mixes them.

Effluent released on the reef flat is influenced first by current patterns generated there and then passes into the influence of reef margin and reef front water transport systems. After some mixing because of wave attack in these zones, the remaining effluent is carried offshore where it joins the currents that dominate the water mass over the terrace and slope.

REEF FLAT AND UPPER MARGIN

Prior to plant startup, a series of reef flat stations were established at the proposed outfall site near Transect B and along the coastline towards both Transects A and C (Fig. 3). Current patterns were investigated by releasing fluorescein dye at these stations. The dye powder was sewn into cloth bags and buoyed. Movement of the dye was timed and plotted on scaled area charts and in some cases recorded with time lapse photography. Wind, wave, and tidal data were recorded. The dye study schedule was set to include both high and low tide stands and to cover ebb and flow.

The same methods were used to study changes in current pattern induced by the release of plant effluent after startup of Tanguisson No. 1. Dye releases were then concentrated at the stilling well of the plant outfall and around the intake channel. Construction of Tanguisson No. 1 was under the jurisdiction of U. S. Navy Public Works and requests were made to the Officer-in-Charge of Construction for current studies that might have been made in the area during the planning stages. Although some offshore and inshore dye studies had been made, little data could be found to indicate the results of the study. One unidentified site plan was located that showed a series of arrows drawn on the reef flat that indicate current direction. These arrows show water flowing from the NCS (Naval Communication Station) swimming lagoon across the proposed intake channel and thence seaward at a point directly adjacent to the power plant.

By the time our project began, the contractor had constructed an earth fill causeway parallel to the proposed intake channel. The causeway was used to excavate material blasted loose from the reef margin and reef flat. When the intake channel was completed the causeway was removed. Presence of the causeway and then the completed channel made it impossible for us to determine current patterns over the Tanguisson reef flat prior to construction. However, we have reason to believe that they were as the Navy chart shows in part and in part as discussed below.

Because the Tanguisson reef flat has a slightly raised seaward margin, there are two natural ways in which seawater may encroach on it. Rising tides periodically cover and uncover it, and water transported by wave action may pour over the margin and spread out over the reef flat. The predominant swell direction on Guam is northeasterly. This swell becomes more northerly as it wraps around Ritidian Point. Swells approach the study area consistently from the north and north northwest. As the swells begin to "feel bottom" on the submarine terrace they wrap until they basically approach the shore at right angles. Most break along the margin from the northwest. Currents on the reef flat are generated by water on the platform returning seaward. In the study area, there are six major points where this seaward flow occurs (Fig. 5, I-VI). These are usually natural low spots on the reef margin and have one or more large surge channels associated with them. The recently excavated intake channel provides an artificial escape point through the reef margin (III). Immediately southwest of the intake channel there is an area of deep caverniculous surge channels that covers a broad front opposite the outfall structure and Transect B (IV). This is one of the dominant points for the seaward escape of water from the platform. The natural depression in the margin is 50 m wide and has five to seven major surge channels through it.

The following discussion considers the various currents generated on the reef flat prior to plant startup (Fig. 5). During the somewhat rare times of calm seas (little or no swell), flood tides gradually cover the reef flat and there is a net movement of water shoreward with little or no movement seaward. Dye placed in the intertidal in the vicinity of Transect B tended to form an even stain and spread out from the shore by diffusion of the dye particles. It usually took 30 minutes or more for the cloud to reach the reef margin. Ebb tides under similar conditions (calm sea) show a net movement seaward through the six points (Fig. 5, I-VI). This continues until the Tanguisson reef flat is completely uncovered except for a few depressions that retain water at low tide. Dye introduced at Transect B and opposite the outfall showed a positive movement seaward, on ebb tides, through the cavernous surge channels along the adjacent reef margin (IV). It took a dye cloud an average of 20 minutes to reach the reef margin surge channels.

The situation described above changes somewhat if there is a surf breaking on the margin. On a flood tide, wave transport adds to the net shoreward movement. Dye placed in the intertidal opposite Transect B and the outfall, again showed a net movement seaward due primarily to diffusion. This movement was very slow due to resistance caused by translated waves on the reef flat. The dye patterns tended to oscillate back and forth with each wave surge, just maintaining a net seaward movement. The direction of movement is still toward the surge channel sector opposite the plant (Fig. 5, IV). During high surf conditions (2 + m) it often took the dye cloud up to 60 minutes to reach the reef margin. A combination of ebb tide and wave transport resulted in the same oscillatory movements of dye clouds but the net movement to the surge channels at the reef margin was somewhat faster, about 20 to 25 minutes, depending upon the magnitude of the surf. There are times, during strong west winds, when some of the dye spreads northeast and enters the intake channel of the plant.

Figure 6 shows conditions that now exist since startup of the Tanguisson Power Plant. Water that formerly entered the intake channel from the adjacent reef flats still does so but the strong rip current that moved seaward before plant startup has been reduced somewhat because of currents generated in the channel by the power plant's circulating pumps. Except at the surface on the seaward end, there is now a net movement of water in the intake channel toward the plant.

Current patterns opposite the outfall structure have been modified in speed but not direction by plant effluent (Fig. 6). Circulating water is released in a stilling well at the intertidal. The effluent wells up onto the reef flat and moves seaward. During low tides and periods of low surf, there is a well-defined stream of water that flows in a direct line seaward. It takes 10 minutes or less for dye released at the stilling well to reach the margin. Effluent enters the reef margin and pours seaward through surge channels. During low spring tides, the effluent forms cascades off of the reef margin into surge channels. At high tides and periods of high surf, the effluent stream is interrupted at the reef margin by wave transport. At this time, part of the stream occasionally turns south and may exit at the second set of surge channels near Transect C (Fig. 5, V & VI). The larger portion of the effluent merges with part of the incoming wave transported water and escapes seaward through surge channels opposite the plant in a series of pulses between wave crests.

LOWER REEF MARGIN AND FRONT

The lower reef margin and front are essentially transition zones between the reef flat and upper margin water masses and those of the terrace and seaward slope. Dye studies were also used in this area but were concentrated where the reef flat current studies indicated exit of water from the reef flat.

Except in the natural low areas north of Transect C (Fig. 5, V & VI), where there is a strong seaward rip current during high tides and surf, dye releases on the lower reef margin and upper reef front result in slowly spreading stains that move parallel to the surfline and in the direction of the prevailing current over the submarine terrace. A suspended particle would tend to be swept back and forth over the margin and upper front by wave surge and at the same time be carried slowly along shore because of the influence of offshore water movements. Such a particle describes a zigzag pattern. This type of movement results in considerable mixing due to wave attack. No changes in this pattern were observed after plant startup.

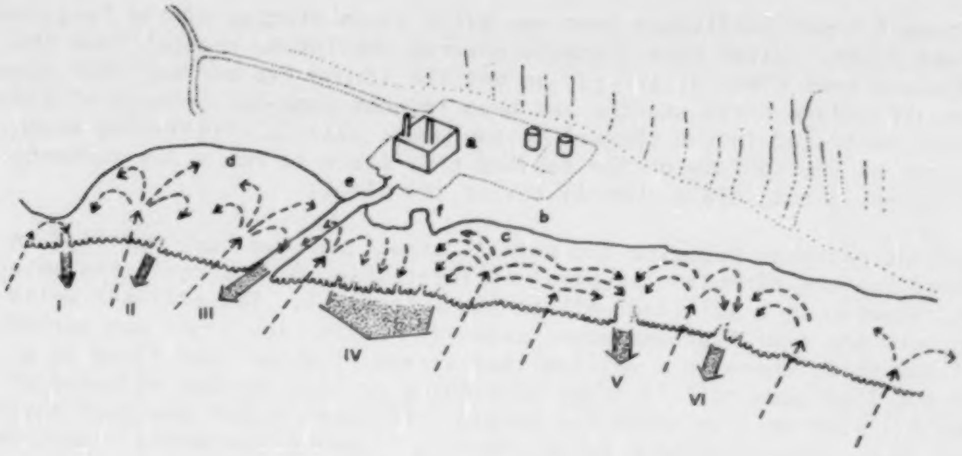
a
b
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Figure 5   Current patterns on the reef flat prior to release of effluent

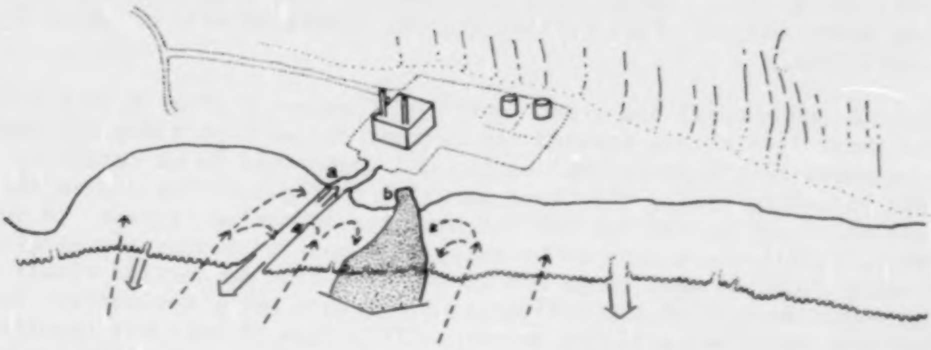


Figure 6   Current patterns on the reef flat after release of effluent

The most consistent direction of movement along the reef margin is to the southwest. West winds and strong tidal shift may set this water to the northeast on occasion.

SUBMARINE TERRACE AND SEAWARD SLOPE

These areas tend to be dominated by the northwestern branch of the North Equatorial current that swings around Ritidian Point, and by tidal currents.

A Hydroproducts Model 502 and three TSK Model 101 current meters were anchored at various depths and along selected transect stations to determine set and drift of currents over the terrace and slope. These data were to provide information on the movement of the effluent plume once it passed over the reef margin and front. Over 1600 hours of current meter data was recorded from Transects A and B at depths of 5, 10-14, 23 and 30 m. All months of the year (1969-1971) were monitored except March, May, September, and November.

Single current meters are anchored devices, that provide only data for a single stationary point. Drift crosses were used to track offshore water masses. These devices provide a better idea of potential plume transport. The drift crosses were set for one, five, and ten meter depths and released along Transect B. The casts were made from small boats and their tracks plotted with hand bearing compass lines of position on known shore points. Fifty drift cross casts were made from October 1970 to July 1971. Casts were made during all months of the year except August, September and November.

Analysis of the current meter tapes showed considerable variation between the TSK meters and the Hydroproducts meter. Basically the TSK meters showed a bidirectional flow at Tanguisson while the Hydroproducts instrument indicated a unidirectional flow. We feel confident that the bidirectional flow is a truer picture. Because there was some question about data gained from in situ meters, we elected to use more drift cross data than originally planned. These data tend to bear out the bidirectional flow.

Mean current direction obtained from current meters is plotted in Figures 7 to 11. Data on the upper submarine terrace (5m) nearest to the effluent release point are shown in Figure 7. The basic directions are on a northeast and southwest axis. The numerous small easterly components are the result of wave surge operating very nearly at right angles to the current axis. Figure 8 shows the current directions in the transition zone between the lower terrace (10m) and upper slope (14m). This region shows a dominant southerly component with considerable representation in southeast quadrants. These data were taken with the Hydroproducts meter and the north to northeasterly components are less well represented here than in the upper terrace (Fig. 7). Again, the easterly components reflect wave surge against the current meter vanes which are normally set either northerly or southerly with the prevailing currents. Figure 9 shows the resultant directions of current for meters set on the mid to lower slope regions (23m). All measurements at this depth were taken with the TSK meters and the data show equally numerous northwest-northeast to southwest-southeast components. The Hydroproducts meter was set several times at the bottom of the slope (30m) and again showed the odd truncated pattern with very little northerly current evident (Fig. 10). We are uncertain at this point why the Hydroproducts meter is unresponsive to northerly components, but suspect a calibration problem. When the data from all stations are combined and mean directions calculated, the pattern shown on Figure 11 emerges. Here the basic current direction lies from northwest-northeast to southeast-southwest. The most common direction is southerly but may be somewhat biased due to the inclusion of data from the Hydroproducts meter.

The current speed data also showed considerable variation between the two types of meters. The TSK meters showed generally lower velocities than the Hydroproducts meter. TSK readings rarely exceeded 0.3kt., the majority were less than 0.15kt. and included numerous zero readings. The Hydroproducts meter showed a range from 0.1 to 0.8kt. with no zero readings. The majority of the readings were grouped around 0.4kt.

We feel that current direction and possibly velocity is correlated with Guam's semidiurnal tides. There are numerous local meterological and hydrographic phenomena that influence the degree of fit of this correlation. Figure 12 shows a relatively close fit of current direction with tide shift. In general, we found that on ebb tides, the current ran to the north or northeast. On flood tides, we encountered a higher frequency of southerly drifts. Some lags or shifts may be seen around the tide turns on Figure 12. Figure 13 shows that on occasion, current direction did not shift with tide for several successive cycles. In the case of Figure 13 the tide ran continuously in a southerly direction. Figure 14 demonstrates the same over-riding of tidal shift but with northerly components dominating. Similar data are reported by Jones and Randall[4].

Drift cross data also suggest that currents in the Tanguisson area move along a basic northeast to southwest axis. Figures 15-17 show direction of drift indicated by 1m, 5m and 10m drift crosses. The occasional strong westerly sets are resultant vectors between the northeast wind and tidal shifts to the north. Due east or west vectors also occur temporarily during times of tide change.

Again there is frequent apparent correlation between tide changes and changes in current direction. But as in the case of current meter data,

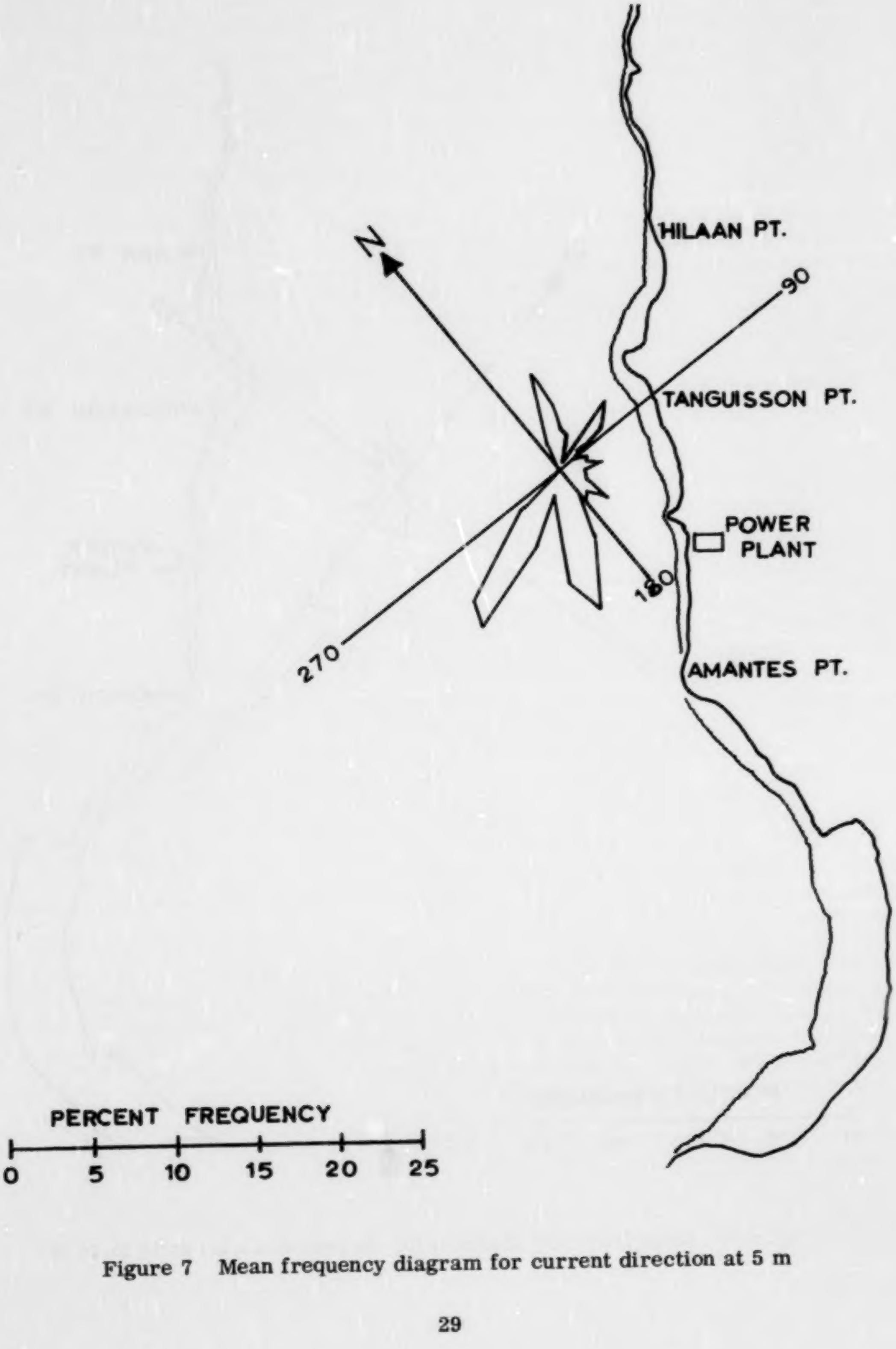

HILAAN PT.
TANGUISSON PT.
POWER PLANT
AMANTES PT.
N
90
180
270
PERCENT FREQUENCY
0
5
10
15
20
25

Figure 7 Mean frequency diagram for current direction at 5 m

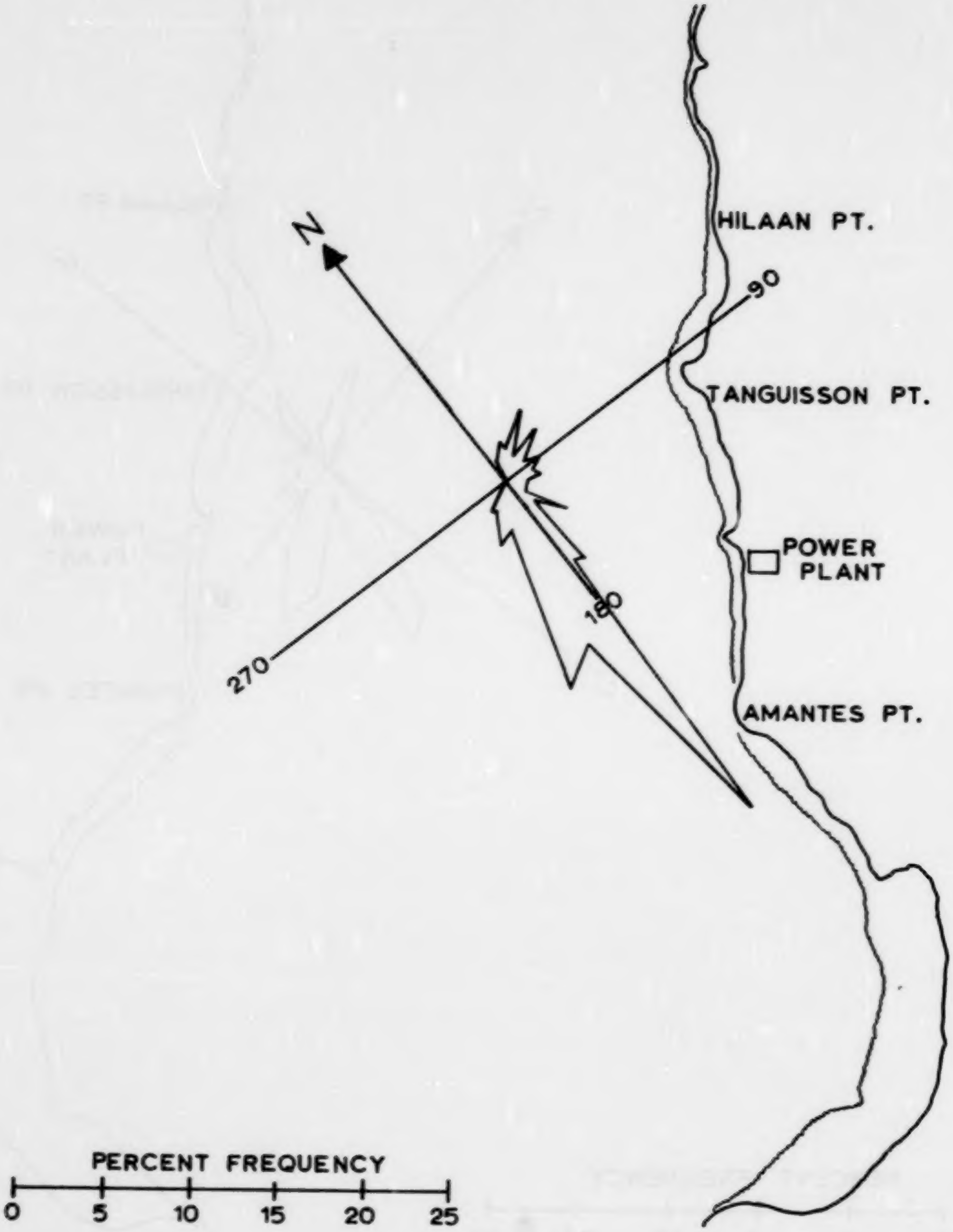

HILAAN PT.
TANGUISSON PT.
POWER PLANT
AMANTES PT.
N
90
180
270
PERCENT FREQUENCY
0
5
10
15
20
25

Figure 8 Mean frequency diagram for current direction at 10 to 14 m

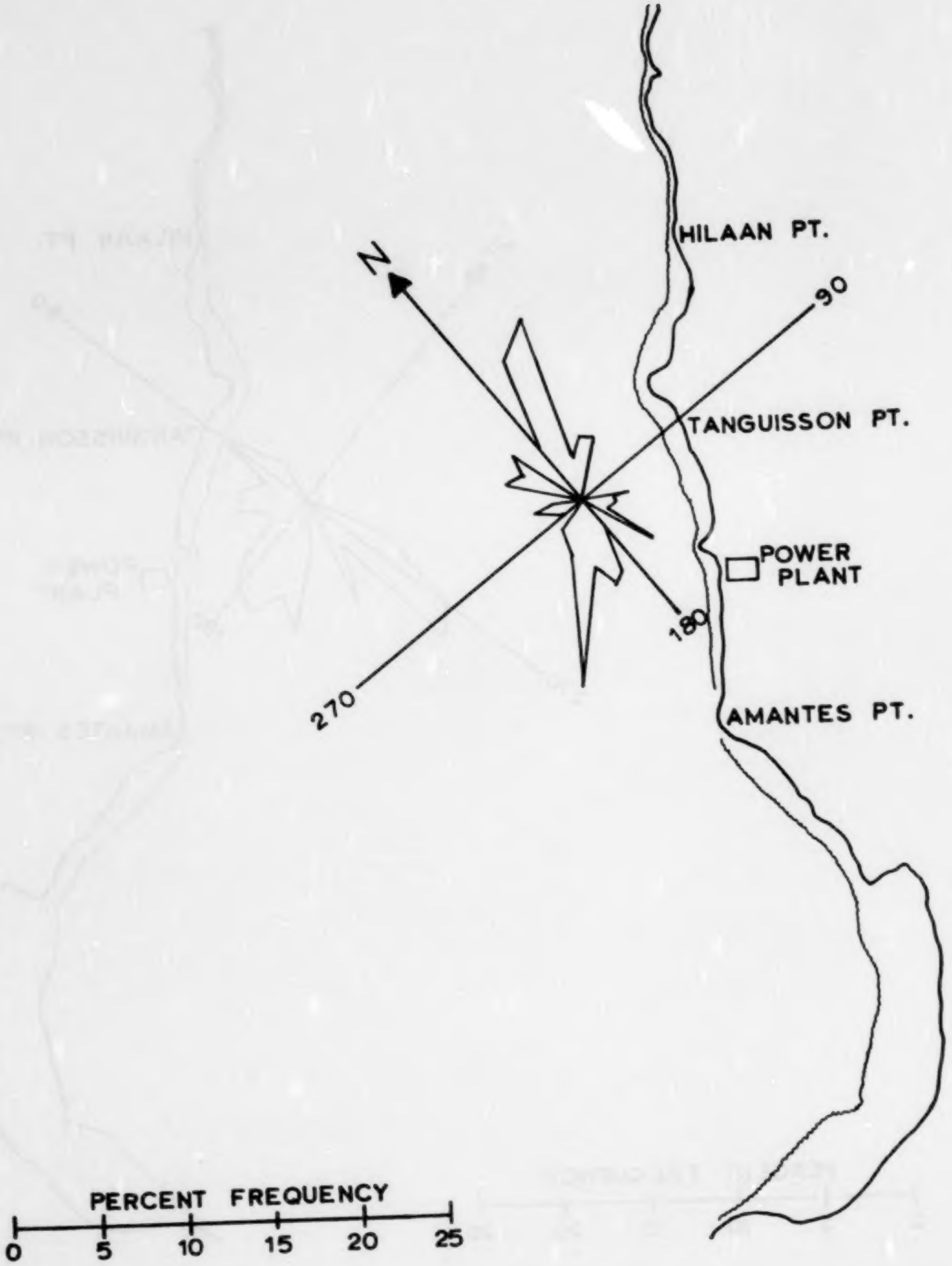

HILAAN PT.
N
90
TANGUISSON PT.
POWER PLANT
180
270
AMANTES PT.
PERCENT FREQUENCY
0
5
10
15
20
25

Figure 9 Mean frequency diagram for current direction at 23 m

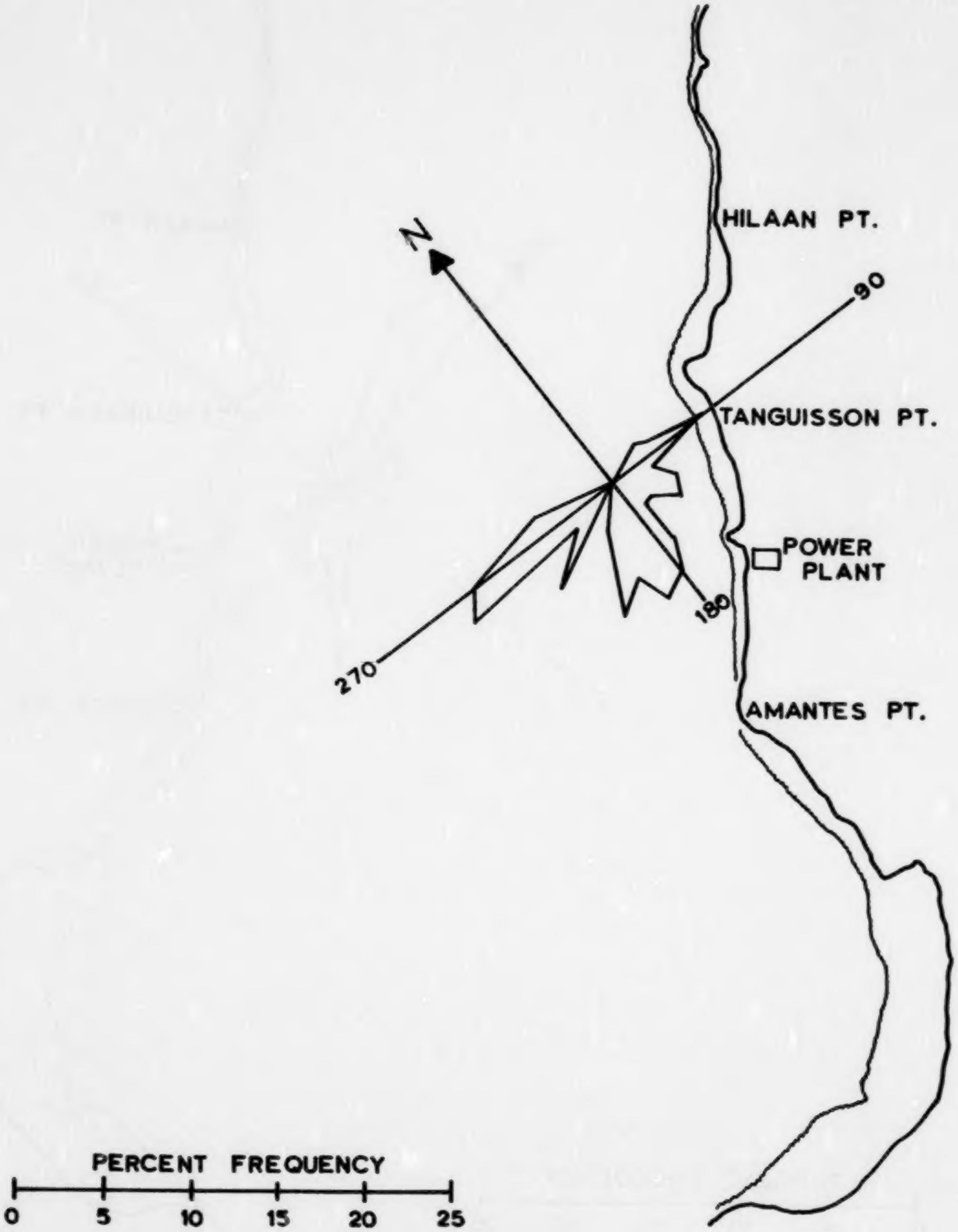

N
HILAAN PT.
90
TANGUISSON PT.
POWER PLANT
180
270
AMANTES PT.
PERCENT FREQUENCY
0
5
10
15
20
25

Figure 10 Mean frequency diagram for current direction at 30 m

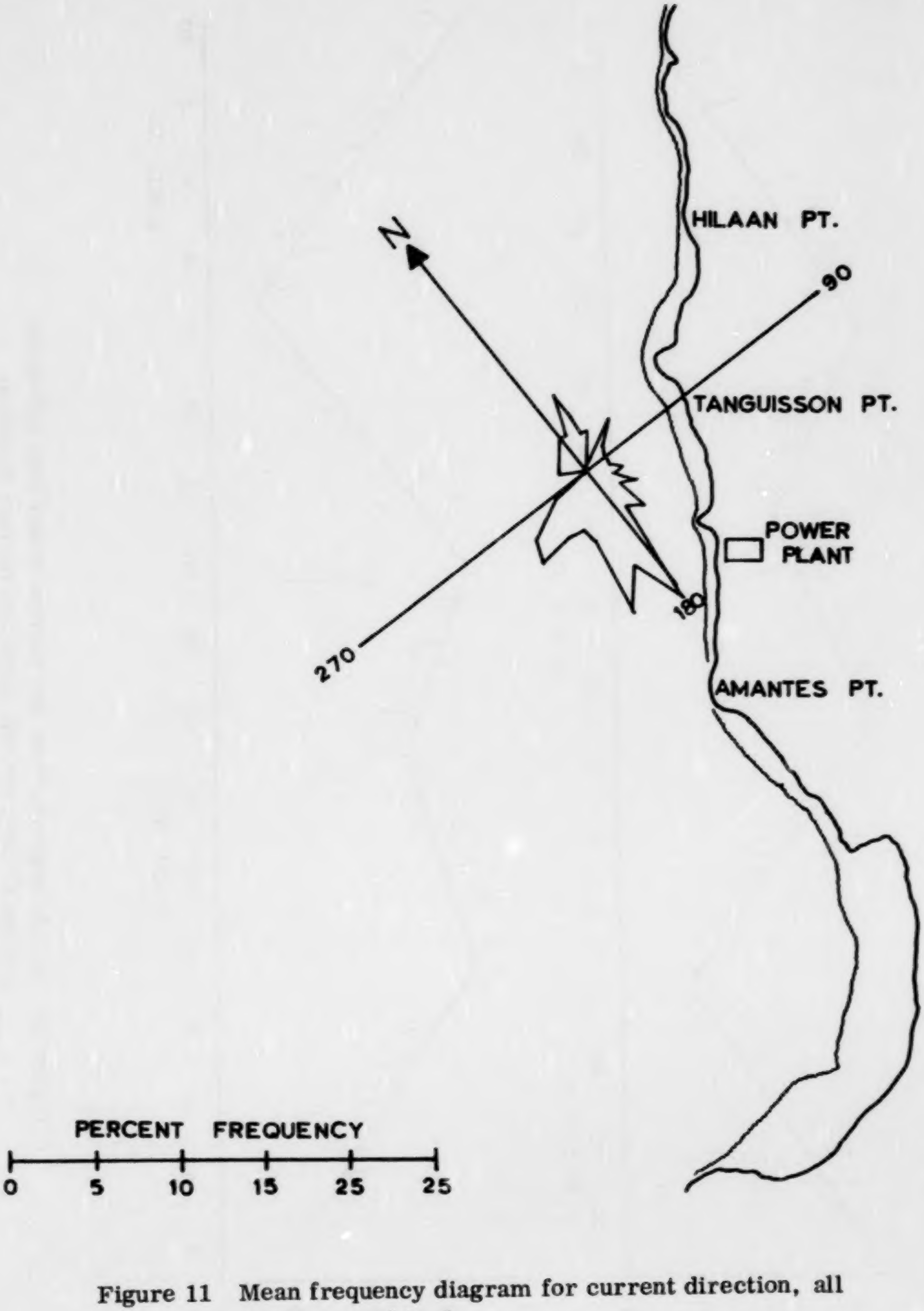

HILAAN PT.
N
90
TANGUISSON PT.
POWER PLANT
180
270
AMANTES PT.
PERCENT FREQUENCY
0
5
10
15
25
25

Figure 11 Mean frequency diagram for current direction, all stations combined

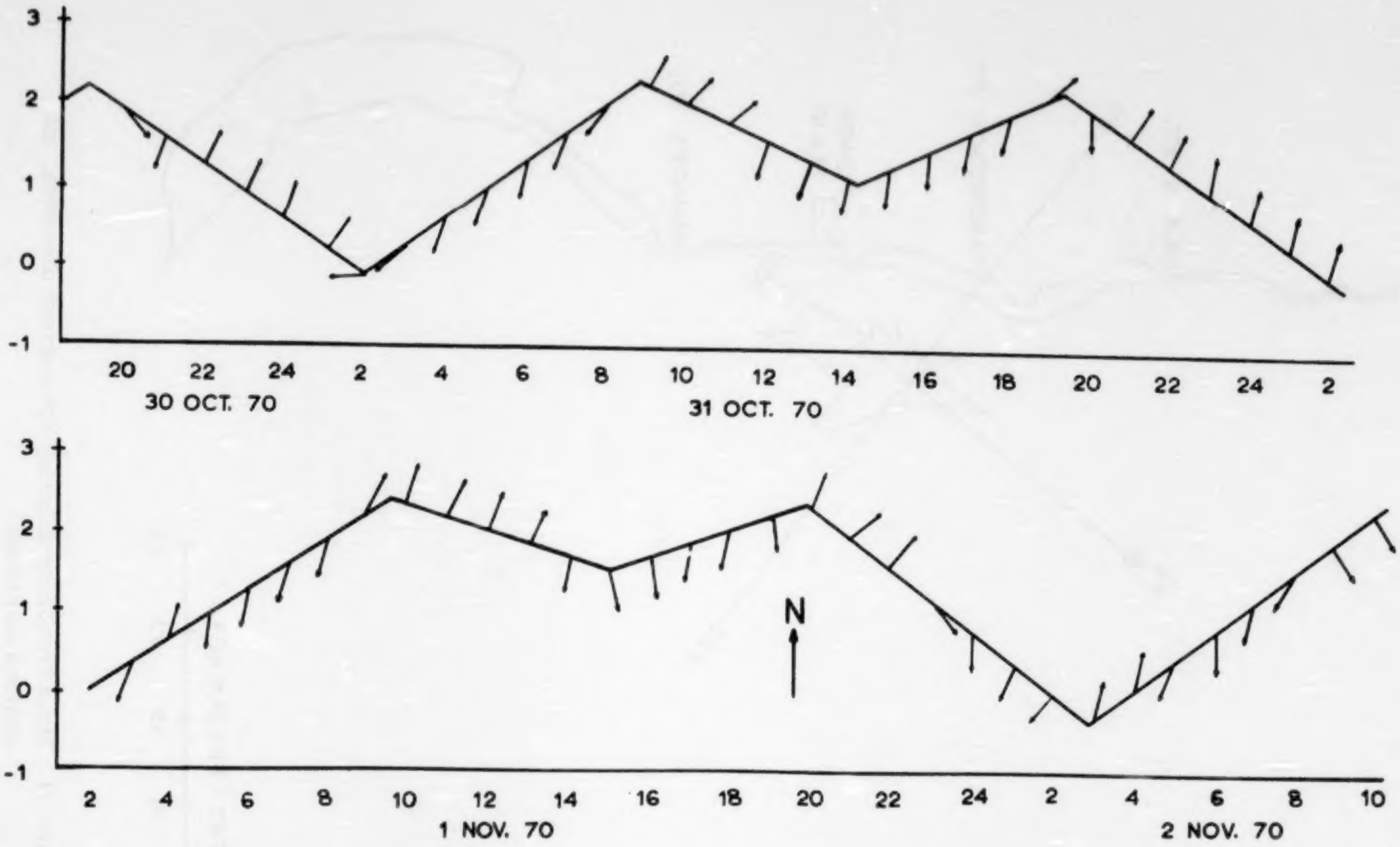


Figure 12 Sample segment from one current meter tape indicating a close fit between tide cycle and current direction

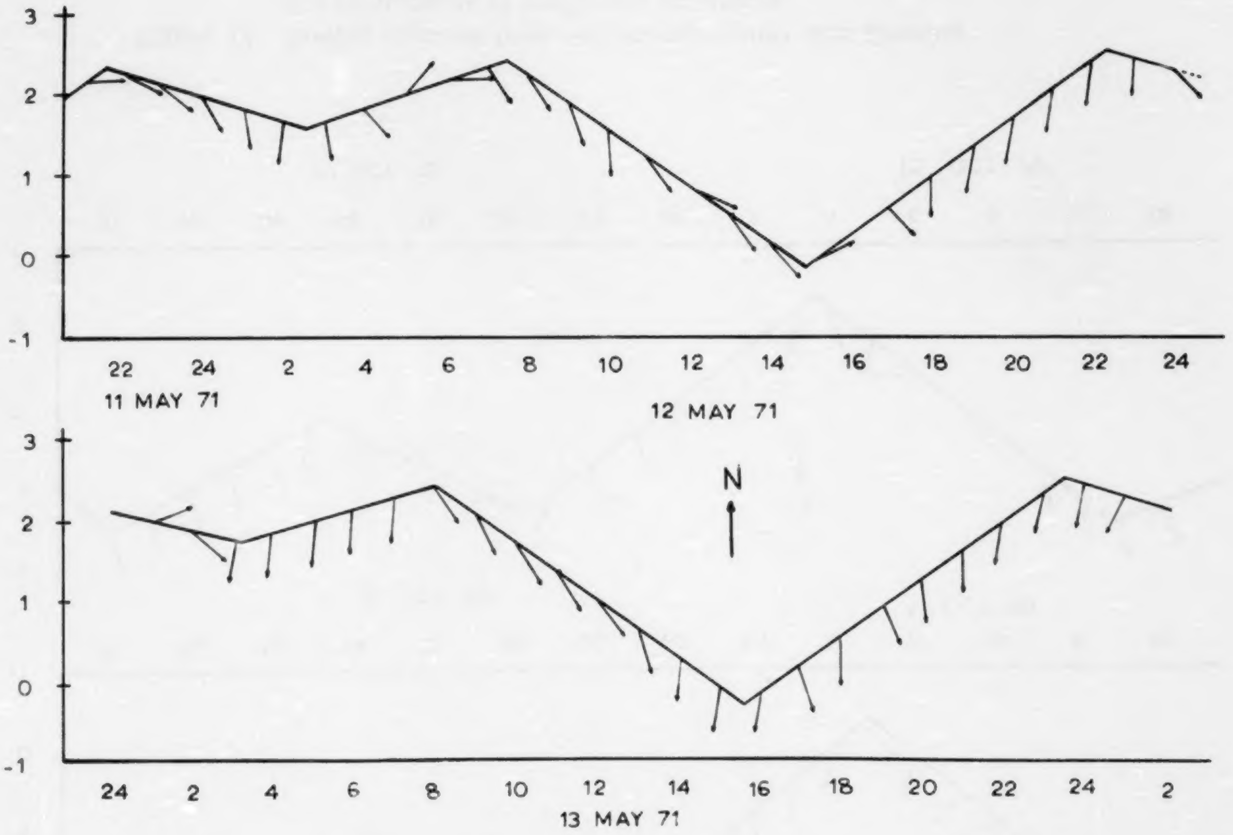


Figure 13 Sample segment from one current meter tape showing a predominance of southerly components

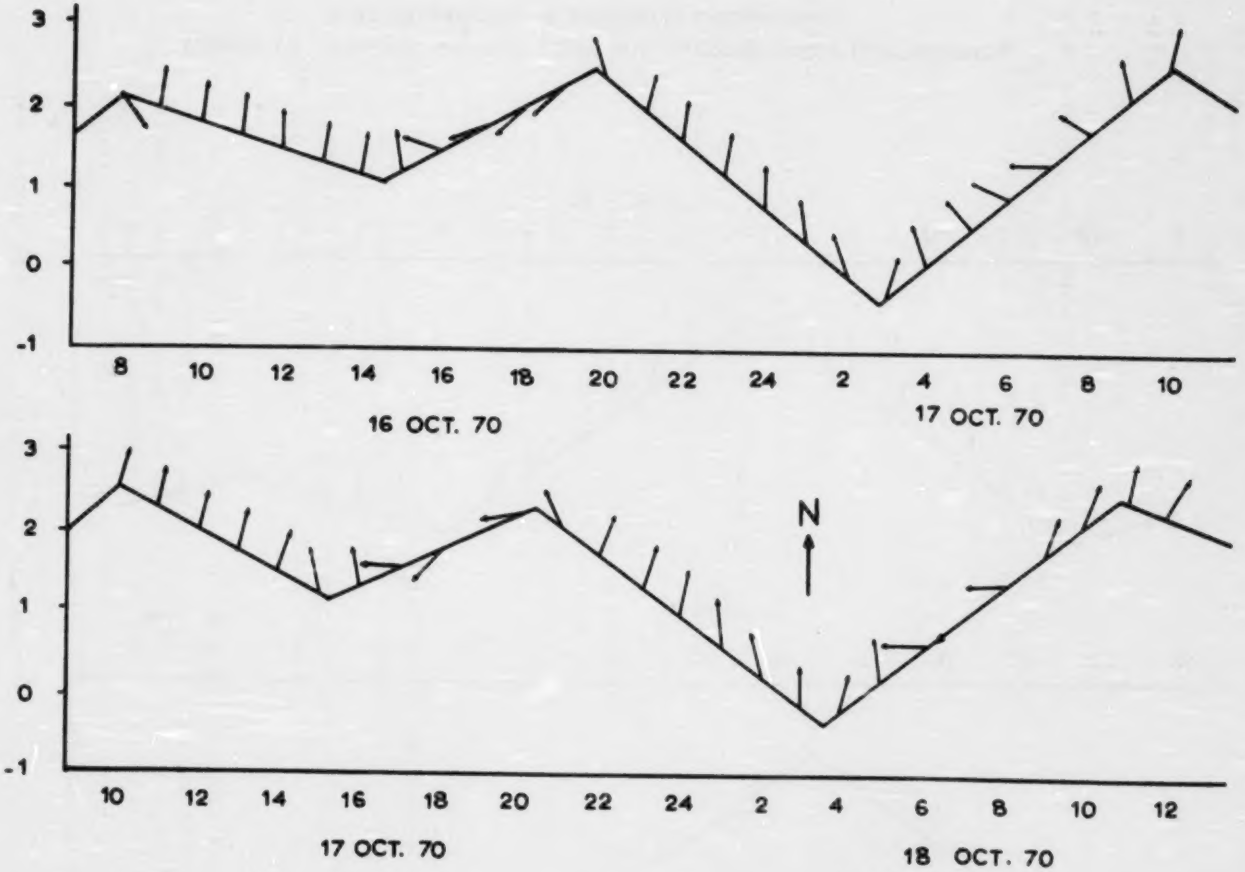


Figure 14 Sample segment from one current meter tape showing a predominance of northern components

current shifts may precede or lag behind tidal shifts or fail to change at all.

In general, the drift cross patterns roughly approximate a northerly drift on ebb tides and a southerly one during floods. Drift numbers 16 and 18 (Figs. 15-16) failed to follow the pattern. Both drifts showed definite northerly directions during floods. The two casts were made in July when the rainy season starts on Guam. At this time tradewinds often break down and the strength of the North Equatorial Current may be reduced. The tide change during the drifts was from a higher low water to a lower high water thus producing a weak flood. Both tide changes were preceded by relatively strong ebbs from a higher high water to a high low. Therefore the northerly flowing currents from the previous ebb may have persisted through the next weak flood.

Drift cross observations indicated a range of current speed from 0.1 to 0.6 kt. with very few zero readings. The mean of the combined drift cross speeds was 0.2 kt.

In 1971, the U. S. Navy Oceanographic Office sponsored a series of current measuring stations at Tanguisson Point and nearby Hilaan Point to the north. This study was conducted in two parts, one survey in the "winter" and one in the "summer". The winter measurements were taken in February 1971 (Anon.[5]). The current meter set off Tanguisson Point showed:

> "....pronounced movement to the northeast and southwest, and observations are evenly distributed in these two directions. Tidal movement shows as a factor when plotted against monitored current, but ocean currents generated by storms at long or short distances from Guam are of greater impact than the tide and generally mask tidal fluctuations."

Dye studies conducted at the same time showed general northwest-northeast and southwest currents that agreed with current meter data.

The Navy's summer survey was conducted from August to September 1971 Huddell et al[6]. The report summarized the previous winter data as follows:

> "Current speeds from the Tanguisson Point meter ranged up to 0.75 knot but they were most frequent between 0.05 and 0.25 knot. Most of the currents flowed northeast and southwest, with northeasterly flow being predominant. Progressive vector diagrams do not reveal any correlation between direction of flow and tidal phase."

This summary contradicts somewhat the discussion in the winter report.

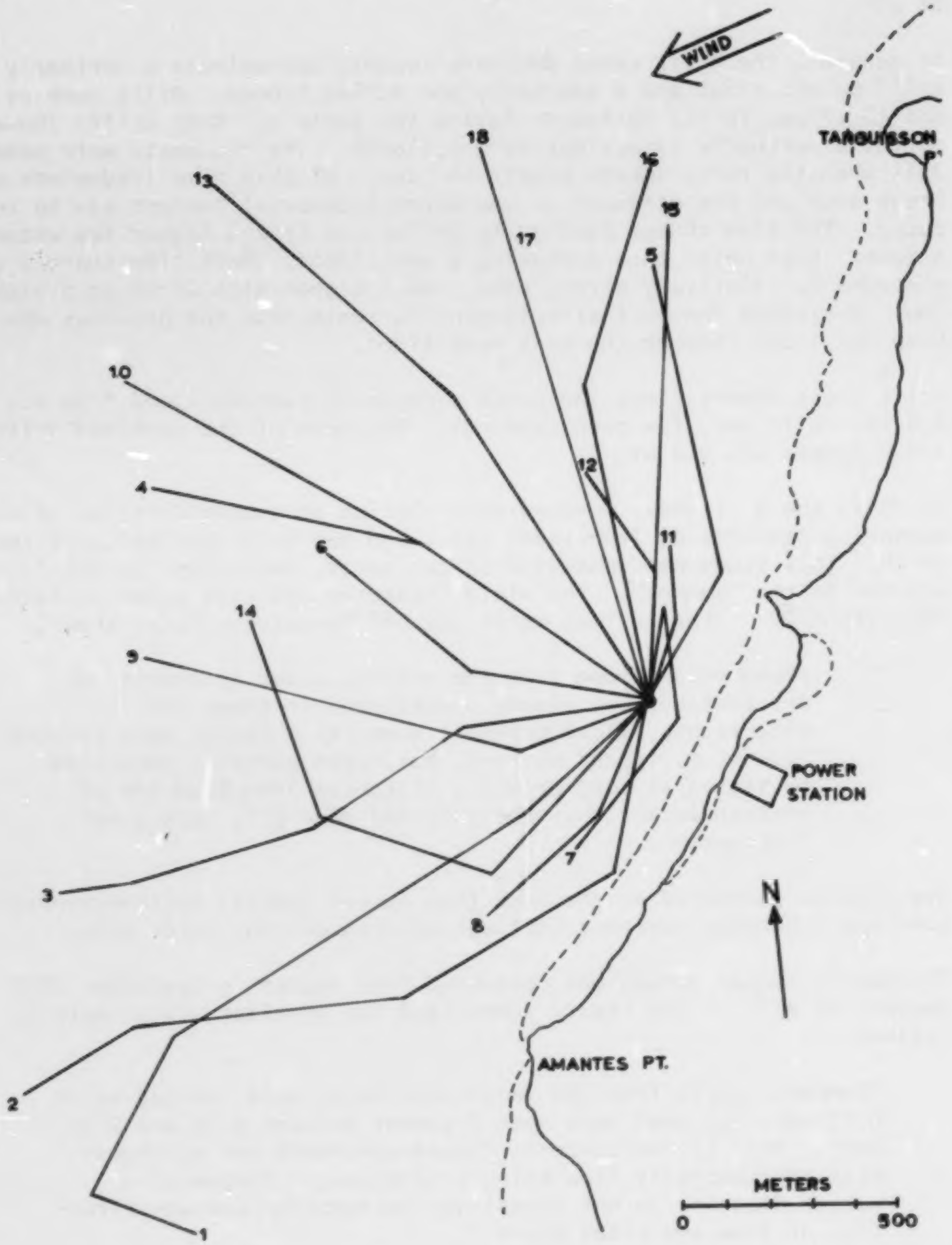

WIND
TARGUISSON P'
18
16
13
15
17
5
10
12
4
11
6
14
9
POWER STATION
7
3
N
8
AMANTES PT.
2
METERS
0
500
1

Figure 15 One meter drift cross casts

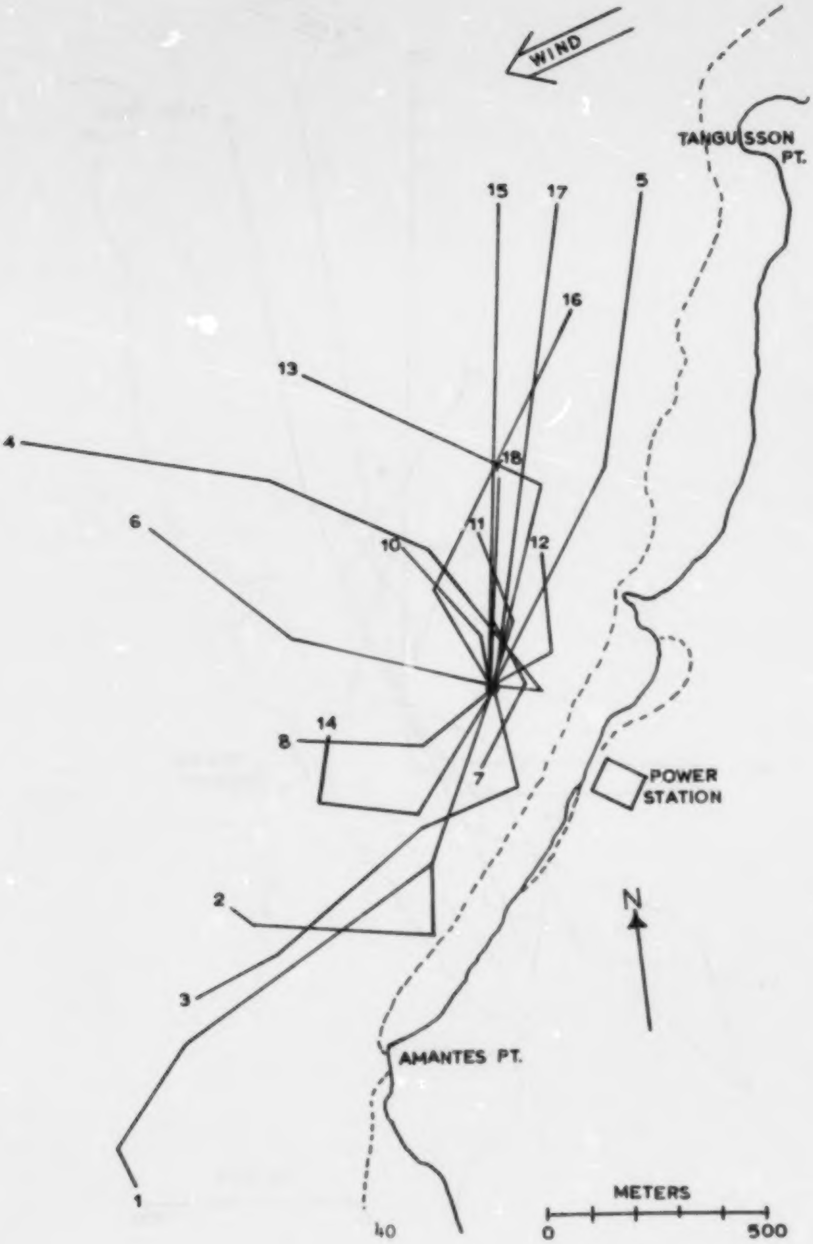

WIND
TANGUISSON PT.
15
17
5
16
13
4
18
6
11
10
12
14
8
7
POWER STATION
2
3
N
AMANTES PT.
1
40
METERS
0
500

Figure 16 Five meter drift cross casts

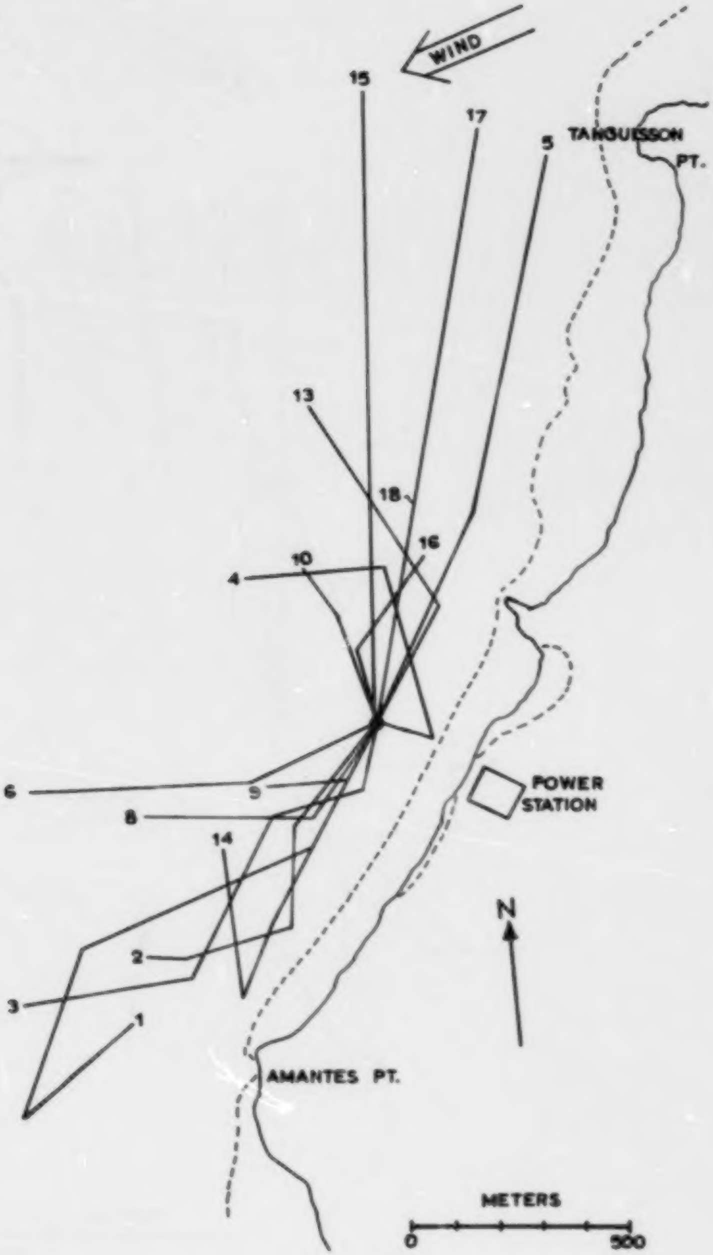

WIND
15
17
5
TANGUISSON
PT.
13
18
16
10
4
6
9
8
14
2
3
1
POWER
STATION
N
AMANTES PT.
METERS
0
500

Figure 17 Ten meter drift cross casts

The summer report went on to describe the August to September current meter sets at Tanguisson and Hilaan Points. The Tanguisson meter suffered a mechanical failure but the first hours of operation were in basic agreement with the winter readings at Tanguisson and the summer readings at Hilaan Point. The Hilaan Point meter showed speeds of up to 0.4kts. but usually less than 0.2kt. A progressive vector based on 66 hours of observations showed direction shifts between southwest and north-northeast resulting in a net westerly drift.

Thirty-eight dye casts were also made during the above summer period along with four drogue casts in the Tanguisson area. Flow was almost equally divided between northeast and southwest. They reported the direction of movement as being unrelated to the tide. Dye releases were observed opposite the power plant over four ebb and four flood periods and one tidal shift from flood to ebb. Of these, we feel that six show a correct tidal related pattern, three were incorrect, and one was inconclusive based on our assumption that current flows southerly on floods and northerly on ebbs. It is interesting that the tidal shift from flood to ebb resulted in a directional change from south to north. All four drogues showed a southerly set with a speed of 0.4kt.

Neither the Navy survey nor our study seems to have satisfactorily answered the question of tidal influence on currents. However, both studies are in agreement about the bidirectional current shifts that occur off Tanguisson Point from northerly to southerly directions.

SECTION VI

TEMPERATURE REGIMES

GENERAL COMMENT

Emery[2] reported seawater temperatures for Apra Harbor, Guam between 27.2 and 29.4°C (2.2°C range). Months with average water temperatures above 28.9°C were July through October. These data are in reasonable agreement with data collected by the Guam Division of Fish and Wildlife from Tanguisson Point. Division personnel take thermometer readings an average of three mornings per month from the reef margin near Transect A. The data are presented in Figure 18 and are a good approximation of the seasonal temperature regime for oceanic water around Guam. For a 10 year period, from 1963 through 1972, the mean water temperature was 27.6°C. Range maxima were 25.6°C, which occurred only once and 29.4°C, which occurred on two occasions (3.8°C max. range). The extremes of mean monthly temperatures were 25.9°C, which occurred once, and 29.0°C which occurred twice (3.1°C range). The range of annual means for 10 years was 27.4 to 27.9°C (0.5°C range). These data suggest that the oceanic temperatures around Guam commonly fluctuate between 26.0 and 29.0°C and rarely fall below or climb above this 3°C range.

As pointed out in the Introduction, seawater at ambient temperature was to be circulated through the Tanguisson Power units at a rate of 17,000 to 28,000 gpm depending upon the number of circulating pumps on the line. According to engineering criteria the temperature of this water was expected to be increased by 12 to 14° F per unit with one pump in operation and about 9 to 11° F with two. Two pumps were to be used about 50 percent of the time, during peak power periods. The policy has changed since the writing of this report, one pump per unit is now used most of the time. If we assume that cooling water in the intake channel is primarily oceanic (mean=27.6°C) and the maximum delta T would be 14° F, then we can predict a mean outfall temperature of 35.4°C (delta T=7.8°C). The range of oceanic circulating water temperatures (approximately 26-29°C) would be increased to 33.8°C at the low end 36.8°C at the high end.

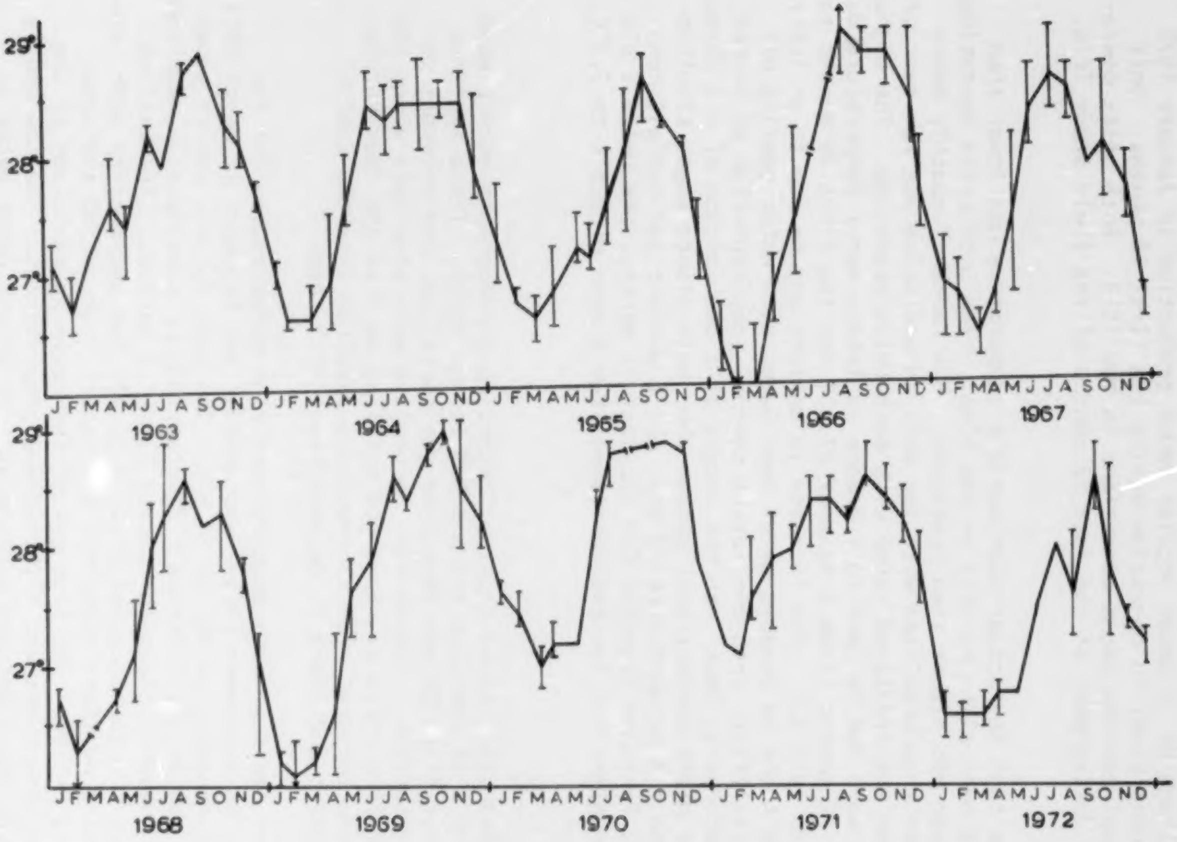


Figure 18 Plot of mean monthly sea surface temperatures for a 10 year period at Tanguisson Point

After Tanguisson No. 1 began generating power, plant personnel provided valuable temperature readings from Control Room thermocouples. These data included intake and outfall temperatures for January 1972 through April 1974 (Fig. 19). Thermometer and thermograph readings were obtained several times from the intake channel and stilling well to verify these data. Tanguisson No. 1 began regular power production in January 1972 and was the only plant in operation during the first 16 months. Unit No. 2 was completed and began operations in May 1973. Both units operated together during most of the last 12 months of the field study (Fig. 19).

Table 1 shows that the actual mean outfall temperature was lower than the predicted mean with one unit on the line. With both units operating, the actual mean was higher than predicted. The range of monthly means was also lower than predicted with one unit in operation but was near or slightly above the predicted range with both units operating. The higher temperatures were due in part to increase in intake water temperature during the last 12 months (from a mean of 27.1°C for the first 16 months to 28.4°C for the last 12). The increase in ambient may be due to an infrequent warming trend in oceanic water near Guam, warm water pouring off the shallow reef flats into the intake channel, recirculation of heated water from both units back into the intake or a combination of all three. Moreover, one might suspect some change when both plants began simultaneous operation. Note on Figure 19 that while ambient and outfall temperatures did increase together for the last 12 months, the delta T did not remain constant but instead increased from a mean of 6.5°C to 7.7°C.

REEF FLAT

Both before and after plant startup, recording thermographs were placed along Transect B at stations B-2 and B-8 (plume axis). These stations are on the reef flat, 20 and 80 m from the shoreline, and adjacent to the outfall structure. Thermometer recordings were also made along the plume axis at 10 m intervals from the stilling well to the reef margin. These data were compared with thermocouple readings from the Control Room of the plant and found to be consistent with them.

Prior to plant startup, mean monthly reef flat temperatures for the months of May to September 1970 (warm months) and February to March 1971 (cool months) ranged from 28 to 30.9°C. The mean for the entire seven month period was 29.3°C. Periodic fluctuations of considerable magnitude were noted on several occasions during low tide periods. The maximum range of these fluctuations was 27.2 to 33.9°C but these times were rare. The former occurred three times and the latter four during the seven month sampling period. The high end of the scale is explained by the coincidence of low tides and high mid-day temperatures. The low end is correlated with low tides and encroachment of ground water escaping

Table 1. PREDICTED AND ACTUAL TEMPERATURE CHANGES OF PLANT EFFLUENT

For Oceanic Water	
10 year mean	27.6°C
10 year range of monthly means	26 (25.9) - 29°C
Assume maximum predicted delta T of 14°F for Tanguisson power units	
Predicted mean	35.4°C (delta T = 7.8°C)
Predicted range of monthly means	33.8 - 36.8°C
Actual intake mean for first 16 mos. (1 unit)	27.1°C
Actual outfall mean for first 16 mos. (1 unit)	33.7°C (delta T = 6.6°C)
Actual intake mean for last 12 mos. (2 units)	28.4°C
Actual outfall mean for last 12 mos. (2 units)	36.0°C (delta T = 7.6°C)
Actual range of monthly outfall means 16 mos. (1 unit)	32.5 - 34.9°C
Actual range of monthly outfall means 12 mos. (2 units)	34.9 - 37°C

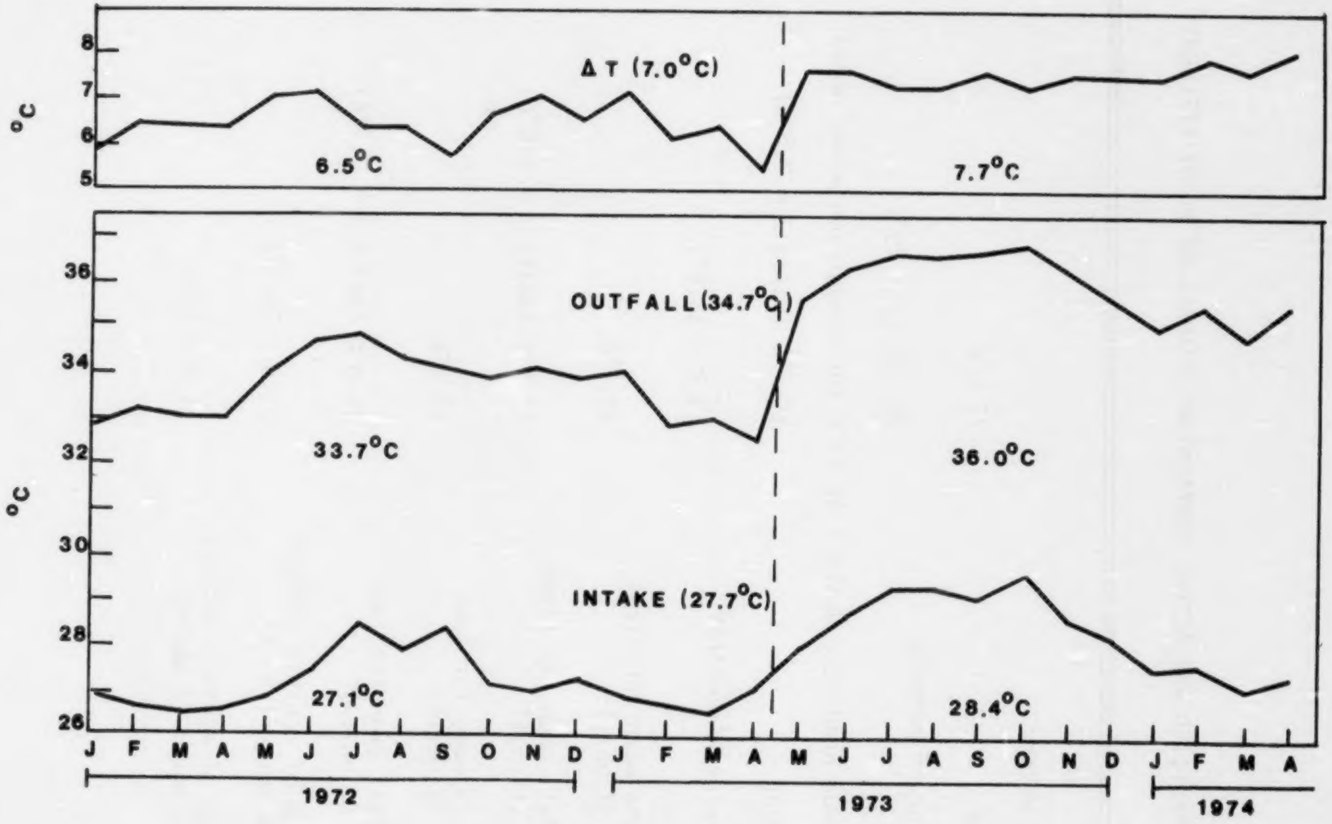


Figure 19 Power plant operating temperatures

along the intertidal from the Ghyben-Herzberg lens. This flow is heaviest after recent rains. Both situations are moderated, as expected, with the next flood tide. These data are in agreement with temperature data from the Agana Bay reef flat in 1969 and 1970 (Jones and Randall[4]). The Agana data show a mean temperature of 29.1°C and a range of 28.0 to 30.5°C for the months of January, February, April, May, September, November and December. The differences between the high ends of the ranges at the two study areas is because of the greater water depth, at low tide, in Agana Bay.

It is apparent then that even in normal (before plant operations) times, temperatures several degrees above oceanic surface temperatures may occur naturally on the reef flat. The normal mean reef flat temperature (29.3°C) tends to run nearly 2°C higher than oceanic (27.6°C), but these conditions are temporary and are relieved during the next flood tide. The power plant, on the other hand, pours a constant volume of heated water across the reef flat adjacent to the plant. Data in Table 1 and Figures 19 and 20 show that reef flat temperatures in the plume were considerably higher than normal reef flat temperatures taken prior to plant operations. The plant effluent mean (both units = 36.0°C) is 8.4°C higher than the oceanic mean and 6.7°C higher than the normal reef flat mean (29.3°C).

Although the high temperatures tend to be moderated somewhat during times of high tide and high surf, these same oceanographic conditions also tend to spread the plume front as it approaches the reef margin and thus exposes a broader and deeper portion of the reef margin biota to water temperatures above normal.

REEF MARGIN AND UPPER FRONT

Recording thermographs were placed at station B-14 (140 m from shore), directly in the surge channels opposite the power plant. Recordings were made both before and after plant startup. This area is subject to violent wave attack and attempts to use in situ instruments has met with only moderate success. Thermographs were lost or damaged on several occasions and we eventually had to abandon our efforts. Attempts to sample the region with hand held thermometers has rewarded the authors with assorted cuts, bruises and broken thermometers. The subsurface waters of the reef margin can only be sampled during times of calm weather when wave mixing is at a minimum and surface stratification maximum. Our inability to place in situ temperature recording devices in this area is particularly unfortunate because it is a critical interface between the coral reef community and the effluent.

Surface water temperatures taken by the Division of Fish and Wildlife are from this zone (Fig. 18). These data were taken along an elevated reef section opposite Transect A (Fig. 3) and therefore are a measure of incoming wave transported water. Temperature measurements taken by project personnel at and around Transect station B-14 reflect both incoming wave transported water and reef flat water escaping through the reef margin surge channels at this point (Fig. 5 IV).

Prior to plant startup, a series of thermograph sets showed a mean temperature of 29.0°C at Station B-14. This is 1.4°C above the oceanic mean recorded at the reef margin near Transect A. The difference, as noted above, is due to reef flat water escaping along Transect B. The range of monthly means was 28 to 30.2°C. Thermograph readings (instruments in 1-2 m depths) in September and October 1972 showed higher temperatures after plant startup. The mean for this period was 30.9°C and the range 29.9°C to 32.1°C. On October 19, 1972 a series of thermometer readings were taken along Transect B. This particular field trip was part of an investigation of a recent coral kill along the margin. Water temperature in the intake channel was 28.6°C. Water in the stilling well and at mid reef flat was 33.4°C. These measurements were taken when the sea was relatively calm (0.5 m swells) and during a low tide that exposed most of the reef flat. Water was cascading off the reef flat and into reef margin surge channels. The temperature of the cascading water was 33.2°C. One meter seaward of this point the temperature was 33.1°C. Effluent was stratified in the upper 0.5 to 1 m of water between wave sets. During times of breaking swells, alternate flashes of hot and cold water could be felt at the bottom of the surge channels. At the midpoint of the reef margin width (Fig. 4), surface water temperatures were 32 to 32.8°C. Thus, although there is a tendency for the low density hot water to stratify as it crosses the reef margin on calm days, a strong swell normally predominates on the reef and results in mixing water into the deepest parts of the surge channels.

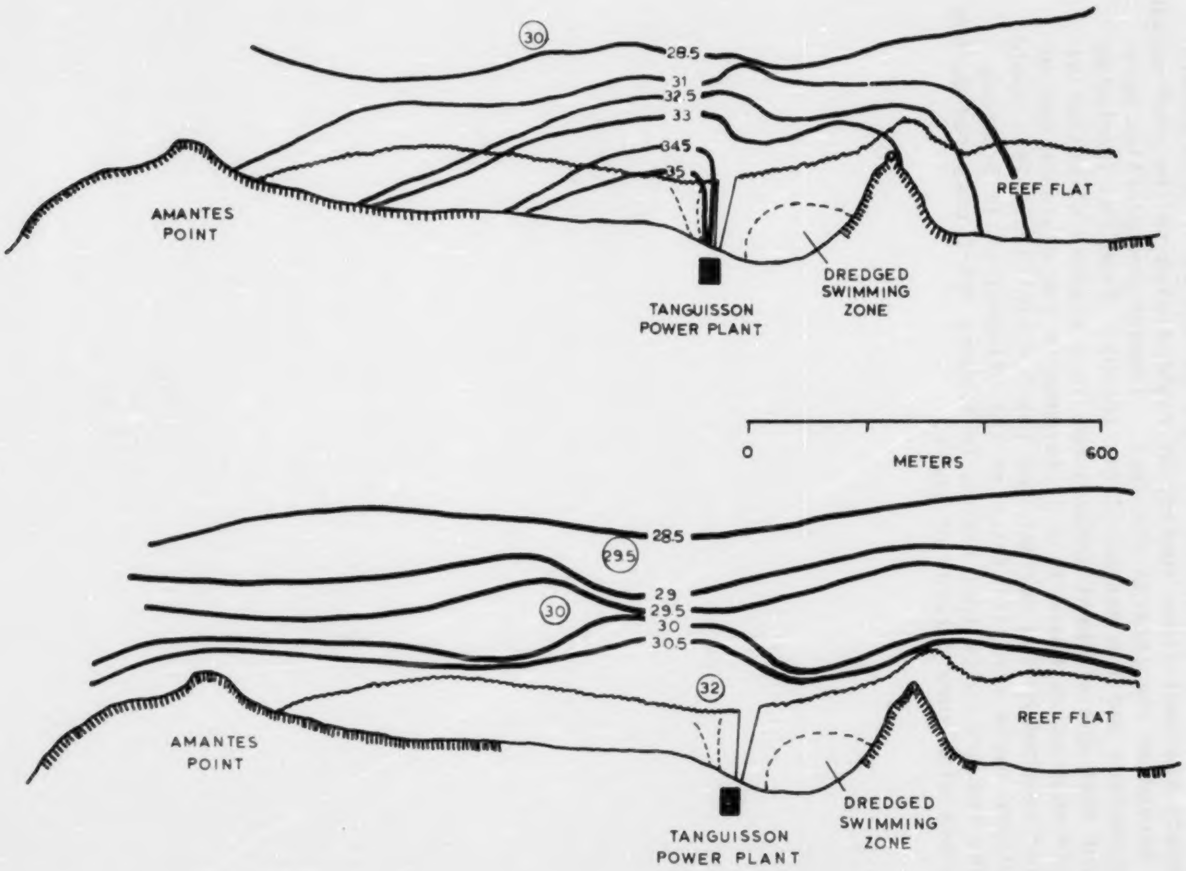
LOWER FRONT AND TERRACE

Water temperatures in these areas, prior to plant operations, were consistent with those shown in Figure 18. The sheer size of this water mass effectively damps out major diurnal fluctuations of ambient temperature.

After plant startup, it soon became obvious that the effluent behaves in a relatively consistent manner. Once the effluent passes through the wave-mixed reef margin and enters the quieter waters of the reef front and terrace, the warm water tends to restratify in the upper 1 m of the offshore water mass (Fig. 27). When strong currents are in motion, this plume drifts with the prevailing current either to the northeast or southwest. The preceeding current study shows the net movements to be southerly. At these times the plume is diverted seaward as it meets the seaward flowing rip currents at the surge channels north of Transect C

(Figs. 6, III and 21).

A somewhat different condition prevails when current flow and wave transport is reduced or absent. Four studies were made at such times between August and September 1974 (both units operating). The limits of the thermal plume were studied by establishing stations at 10 m intervals along temporary transect lines running at right angles to the reef margin. Transect B served as the control transect. Temperature profiles were made at the surface and 1 m depths (Figs. 20A-H). From the isotherms it is evident that the effluent spreads out in a seaward direction as expected. In most cases there is a difference in the distance out to ambient water reached by the surface and the 1 m profiles. This would seem to indicate rapid stratification of the effluent as it proceeds seaward. The seaward bulge that occurs in Figures 20E-G occurred during a flat calm sea with zero current offshore.


30
28.5
31
32.5
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34.5
35
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT
0
METERS
600
28.5
29.5
29
30
29.5
30
30.5
32
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT

Figure 20 A, B. Surface and 1 m isotherms for August 2, 1974.

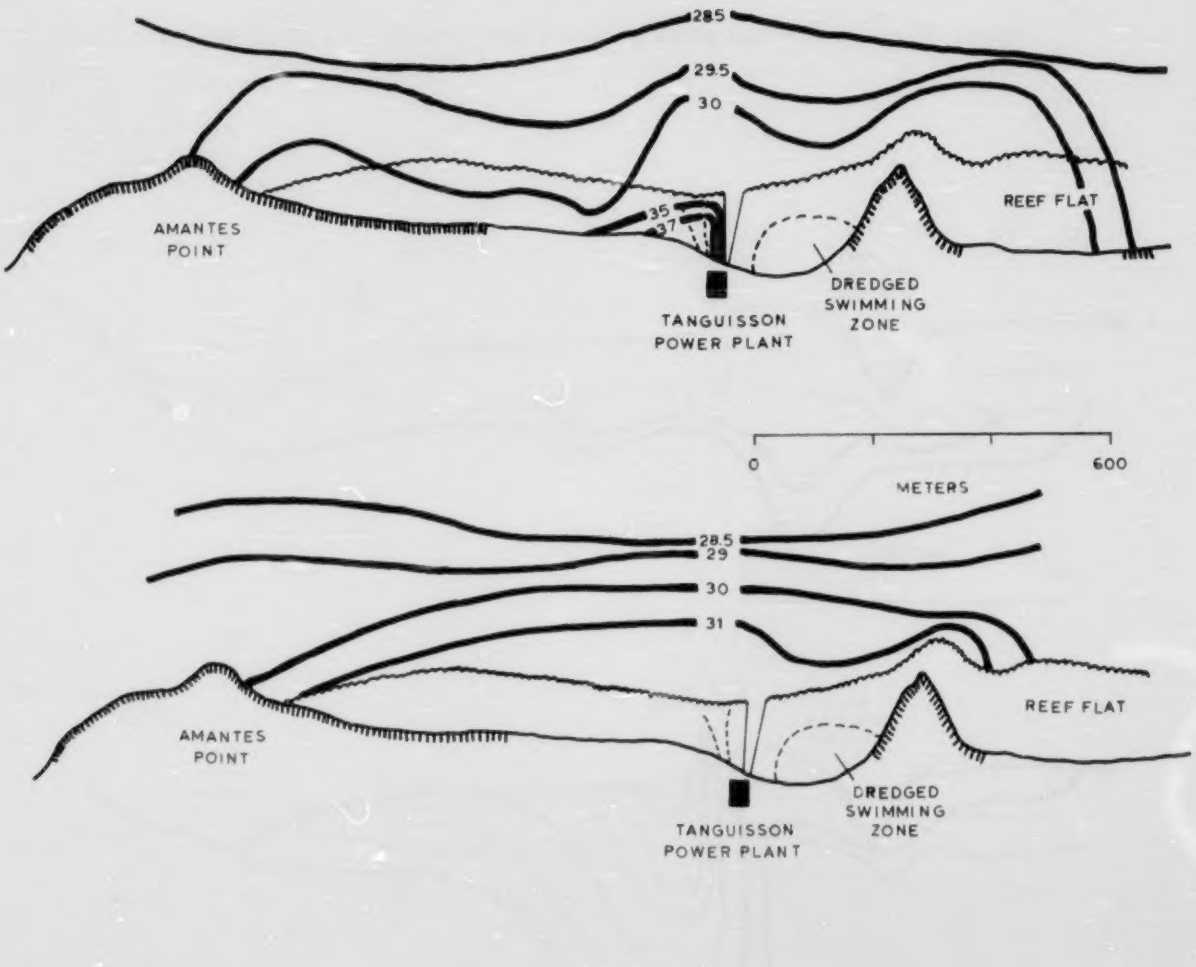
28.5
29.5
30
35
37
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT
0
600
METERS
28.5
29
30
31
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT

Figure 20 C, D. Surface and 1 m isotherms for August 20, 1974.

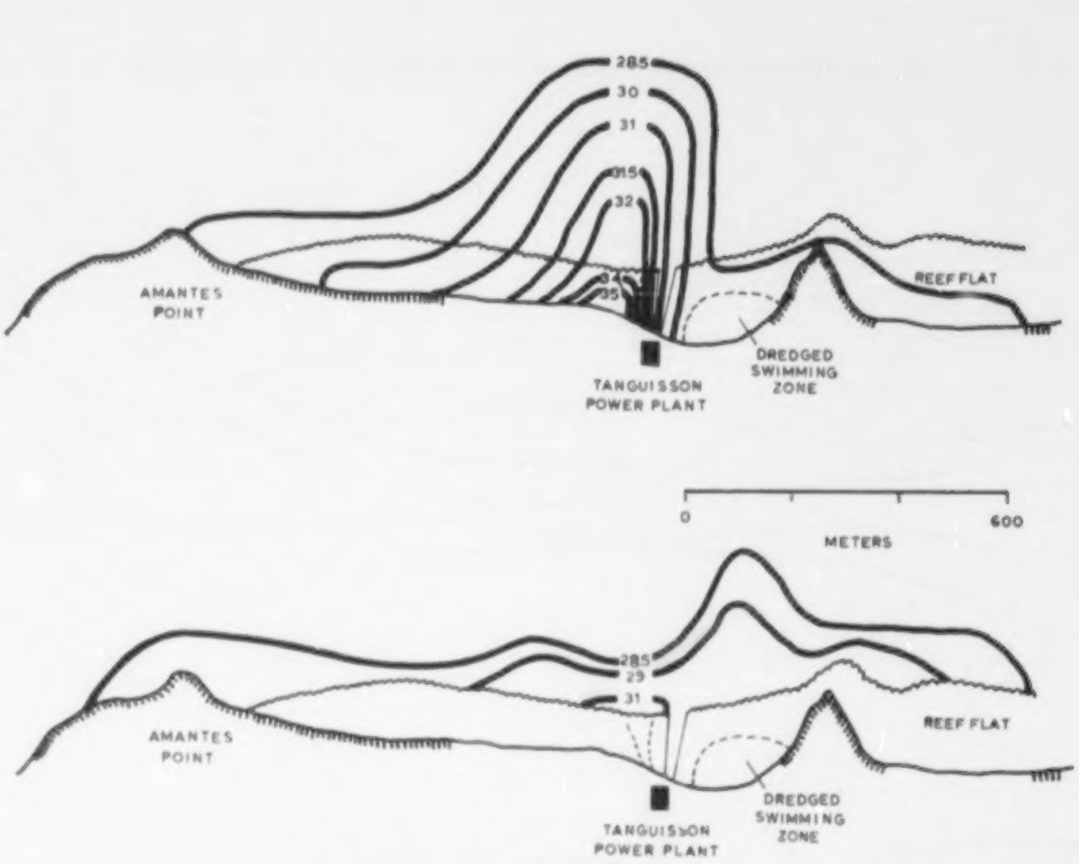
28.5
30
31
31.5
32
34
35
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT
0
600
METERS
28.5
29
31
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT

Figure 20 E, F. Surface and 1 m isotherms for September 5, 1974.

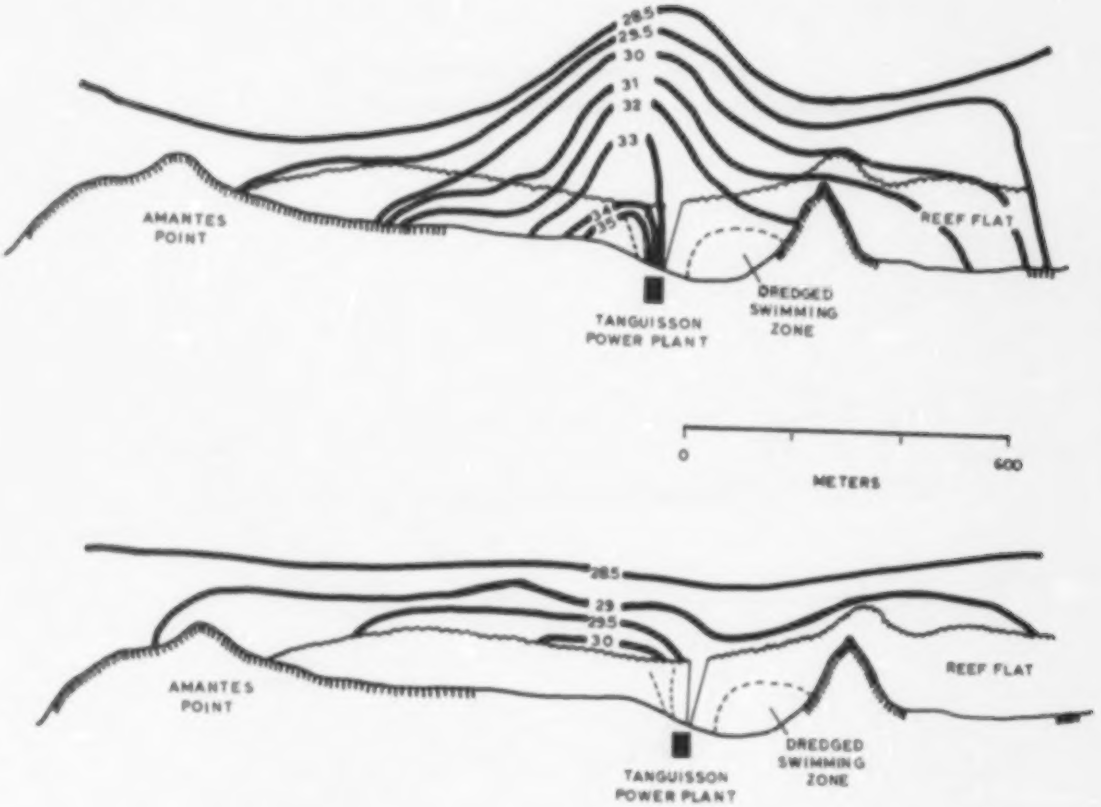
28.5
29.5
30
31
32
33
34
35
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT
0
600
METERS
28.5
29
29.5
30
AMANTES POINT
TANGUISSON POWER PLANT
DREDGED SWIMMING ZONE
REEF FLAT

Figure 20 G, H. Surface and 1 m isotherms for September 12, 1974.

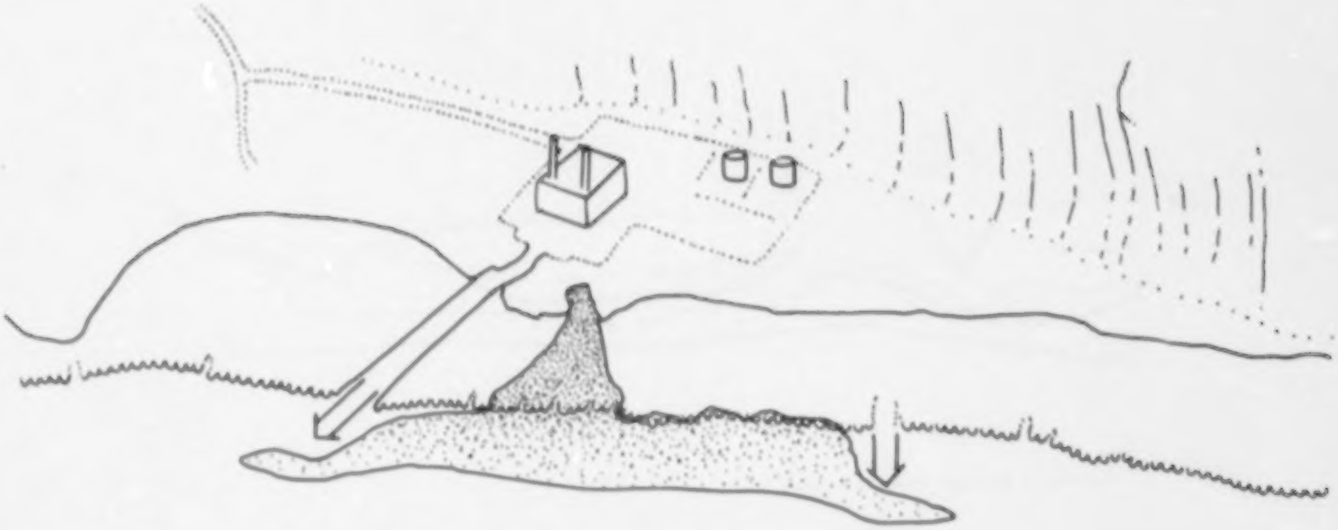

Figure 21 Diagrammatic presentation of the influence of the thermal plume on the reef margin

SECTION VII

CHEMICAL PARAMETERS

SALINITY

Salinity measurements were taken in the intake channel and stilling well and along Transect B. Samples were collected in bottles and analyzed in the Laboratory with a Hytech Salinometer.

A nine month (March to November 1969) sample period, conducted by the Division of Fish and Wildlife, showed that average monthly oceanic surface salinities in the area range from 33.83 to 34.63 with a mean of 34.28°/oo. The only major variations in salinity expected were those of the reef flat environment where ground water escapes from the Ghyben-Herzberg fresh water lens system. The primary intrusion of this water is along the intertidal zone of the reef flat. Salinity is considerably lowered at this point (Table 2). At times, the eggs and larvae of the toad _Bufo marinus_ are found in brackish pools along the intertidal.

Natural freshwater springs are also found beyond the reef flat platform. Several of these springs are evident in reef margin surge channels. Similar springs have also been encountered at various points on the submarine terrace. Sudden changes of temperature are easily distinguished by divers passing through the rising freshwater. During times of heavy flow, shimmering clouds of low density spring water can be seen rising in the water column. Construction of the intake channel has broken through the limestone cap of the reef flat and freshwater also escapes along the channel margin.

The data in Table 2 show a salinity gradient along Transect B from the intertidal to the reef margin. Salinities as low as 1.84°/oo were recorded near shore. The rate of mixing is dependent upon wind, sea and surf conditions and to a certain extent upon the tidal phase. Periods of calm associated with low tides result in low salinities on the inner reef flat. High tides during calm weather often result in a visible lens of fresh water that is carried seaward over the reef margin and onto the surface above the submarine terrace. Table 3 shows that seawater

Table 2. REEF FLAT SALINITIES (0/00). Stations are along Transect B at 10 m intervals from the shore.

			Station Numbers							
Date			B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8
14 Sept.	70	Surface	1.84	27.31	29.29	33.01	31.84	33.99	33.79	33.86
		Bottom	1.98	27.81	29.95	32.86	31.84	33.99	33.79	33.86
15 Oct.	70	Surface	2.89	29.14	31.68	32.72	33.64	34.08	34.40	34.50
		Bottom	4.43	29.11	31.65	32.65	33.89	34.09	34.40	34.50
18 Feb.	71	Surface	5.58	31.17	32.82	33.93	34.43	34.44	34.43	34.43
		Bottom	9.28	31.15	32.92	33.93	34.43	34.44	34.43	34.43
25 Feb.	71	Surface	6.24	33.28	33.89	34.42	34.40	34.54	34.56	34.60
		Bottom	17.18	33.32	34.16	34.42	34.40	34.54	34.56	34.60
2 Mar.	71	Surface	24.40	26.56	29.47	34.54	34.49	34.49	34.49	34.49
		Bottom	23.18	27.34	30.49	32.54	34.49	34.49	34.49	34.49
21 Apr.	71	Surface	14.31	22.65	23.11	29.58	29.26	31.93	33.58	34.22
		Bottom	17.20	23.00	23.11	29.58	29.26	31.93	33.58	34.22
Mean			10.76	28.53	30.21	33.02	32.95	33.91	34.22	34.35

is diluted somewhat in the intake channel. A gradient occurs from the channel surface to the bottom at the intake structure. Salinity changes between the intake and the stilling well are minimal and less than the natural changes that occur on the reef flat.

Table 3. SALINITY DATA FOR INFLUENT AND EFFLUENT (o/oo).

	STATIONS							
Date	Channel Entrance Surface	Channel Entrance Bottom	Intake Surface	Intake Midwater	Intake Bottom	Stilling Well	Mid-Reef Flat	Reef Margin
18 Oct. 72	---	---	33.68	---	33.92	33.92	33.74	33.76
2 Nov. 72	---	---	33.32	---	---	33.76	33.76	33.75
8 Nov. 72	---	---	33.84	33.90	33.93	33.65	33.62	33.63
14 Nov. 72	34.09	34.17	32.73	34.09	34.12	34.76	33.98	34.14
22 Nov. 72	34.06	34.09	30.24	34.12	34.12	33.98	33.99	34.20
Mean	34.08	34.13	32.76	34.04	34.06	34.01	34.00	33.90

OXYGEN

There was no evidence to show that dissolved oxygen values varied significantly from intake to outfall. A sample of data taken in November 1972 is given below.

Date	Intake (mg/l)	Outfall (mg/l)
2 Nov. 1972	6.45	6.50
8 Nov. 1972	7.63	7.77
14 Nov. 1972	6.97	6.98
22 Nov. 1972	7.07	7.00

A reduction of percent saturation of 15 to 20% may be expected at higher outfall temperatures but this change in itself would probably not be of great environmental significance. Dissolved oxygen values of over 7.0 mg/l were higher than expected for oceanic water but were found both in intake and outfall channels.

CHLORINE

Chlorine was used during the first year of operation as a desliming and anti-fouling agent in the circulating water system. The project did not include an investigation of either free or residual chlorine in plant effluent. However the known toxicity of chlorine makes at least a discussion of its use worthwhile.

The consulting engineers for Tanguisson No. 1 recommended from "past experience" a chlorination dosage of 5 ppm chlorine rate for 20 minutes, three times per day. Actual usage was about 70 lbs per day or a little over one ton per month. In this case 23.3 lbs of chlorine was used over a 20 minute treatment period on each of the three working shifts (personal communication, Frank Melder). This produced a theoretical 5 ppm rate ahead of the circulation pumps.

On November 2, 1972, the plant chlorine supply ran out and none was available on the island. It was nearly a month before chlorine was available again. Examination of the water boxes and condenser tubes at this time showed very little sliming or other fouling. We were invited to observe the operation, and strongly urged the plant operations personnel to discontinue use entirely. Plant management decided to reduce the chlorine treatment to one shot per day using about 23 lbs in 20 minutes or about 700 lbs per month. When no loss in plant efficiency was noted, this was further reduced to 12.5 lbs in 10 minutes or about 400 lbs per month. Finally plant management decided to discontinue use altogether. This condition still existed at the writing of this report and no plans are evident for restarting treatment.

The halt in use of chlorine served not only to reduce potential environmental damage but also cut operational costs.

HEAVY METALS

A special request was made by a Project Officer to monitor copper, cadmium, and nickel in the plant effluent. Water samples were taken on three occasions and shipped to the EPA Water Quality Laboratory at Alameda, California for analyses. The data are presented in Table 4.

There is very little evidence to indicate that large quantities of these metals are escaping from the power plant. Copper is obviously higher in the stilling well than in either the intake or offshore water. However,

Table 4. HEAVY METAL ANALYSES. The data are arranged as Cu/Cd/Ni and the units are in ug/l.

Date	Intake	Outfall	Reef Margin Transect B	Reef Margin Near Transect C	Mid-Terrace Transect A	Open Ocean 1/2 Mile Seaward
13 Jan. 72 Current Running North	0.8/≤0.1/1.6	2.1/≤0.1/0.6	0.7/≤0.1/1.1	0.6/≤0.1/1.0	0.6/≤0.1/2.9	0.6/0.3/1.0
4 April 72	0.5/≤0.1/0.8	1.1/≤0.1/≤0.5	0.2/≤0.1/1.1	≤0.1/≤0.1/≤0.5	0.3/0.4/≤0.5	0.9/0.8/≤0.5
23 May 72	1.0/≤0.1/≤0.5	2.9/≤0.1/≤0.5	1.2/≤0.1/≤0.5	≤0.1/≤0.1/≤0.5	≤0.1/≤0.1/≤0.5	≤0.1/≤0.1/≤0.5

this amount does not exceed that shown by Goldberg[7] for open ocean water (3.0 ug/l) and by Alexander and Corcoran[8] for water in the Florida Straits (10 ug/l. total Cu).

Cadmium was present in amounts usually less than 0.1 ug/l. However, cadmium values increased to 0.4 at the mid-terrace station on Transect A on one occasion and went as high as 0.3 and 0.8 ug/l in the open ocean station. This is higher than normal seawater values (Table 4). Contamination is suspected in the taking of these three samples.

Nickel values seemed variable, however, the values near the power plant were often higher than oceanic water.

It is apparent that considerably more sampling would be called for, including replicate sampling from each station, if we are to obtain an accurate picture of heavy metal distribution. The three samples taken were from within the first four months of plant operation and the content of these metals in the effluent might be low and expected to increase.

It should also be noted that the red clay soils of the northern plateau contain all three of these metals. It is not inconceivable that they are introduced by way of the freshwater lens.

SECTION VIII

BIOLOGICAL IMPACT OF EFFLUENT

GENERAL COMMENT

It became obvious in the early stages of this work that the thermal plume would have little influence on the benthos after it passed through the surge zone along the reef margin. Once over the reef front and terrace, the effluent was stratified in the upper one to two meters and offered no threat to organisms below these depths. Consequently, biological surveys along the reef front, terrace, and slope concentrated on the effects of the *Acanthaster* damage and the subsequent recolonization by corals.

The reef flat and reef margin environments were, however, directly impinged upon by the effluent plume and the studies there were concentrated on delineating the effects of the effluent. Biologically, the reef flat was found to be naturally depauperate, while the reef margin was a diverse, rich ecosystem that had remained unaffected by the *Acanthaster* infestation.

ALGAE

A series of quantitative algal transects were made by Dr. R. T. Tsuda from March to July, 1970. Dr. Tsuda found the algal community in all reef zones to be "typical" for these habitats. The only differences were in the *Acanthaster* damaged reef front, terrace,and slope. In these areas, algal species composition was virtually identical to undamaged areas but the standing crop of algae was higher, presumably due to the reduction in live coral cover. No changes were noted in qualitative transects run by Dr. Tsuda in the same areas from May through July 1972, over one year after the power plant began to operate.

Considerable change was noted, at this time however, in the reef flat and reef margin zones where there was obvious influence from the thermal plume.

Table 5 lists the change in species composition encountered over the reef flat and upper reef margin in the immediate vicinity of thermal discharge. Thirty-nine species were encountered before plant operation (Unit No. 1) and only 12 afterward, a 69% reduction in the number of species. The blue green algae became the dominant group present. Species of this group are well known for their role as pioneering species. They are among the first algae to appear and often dominate early successional stages on coral reefs. They are, for example, among the first colonizers of coral coralla after the polyps are removed by *Acanthaster*. As succession proceeds, the species are normally replaced by species from other algal divisions. The blue green species are rarely replaced entirely but are merely reduced in their role as the dominant algal species.

Thus, introduction of effluent from Tanguisson No. 1 effectively reduced the reef flat and upper reef margin algal community to an earlier stage of succession. However, unlike natural perturbations, the effects of thermal effluent are persistent as long as the plant remains operational. Hence, normal algal succession following the initial kill and recolonization does not advance but rather holds at the level of the early pioneering species, the blue greens. Exceptions to this were *Halimeda opuntia*, and *Cladophoropsis membranacea*, green algae; *Dictyota divaricata* and *Padina tenuis*, brown algae; and *Amphiroa fragilissima* and *Polysiphonia scopulorum*, of the red algae. These species all seemed somewhat resistant to plume effluent but, *Cladophoropsis membranacea* seemed to thrive there. This species produced a thick mat within the limits of the plume and showed an obviously lower biomass and patchy distribution outside of the plume during its growing season. Prior to plant operation, *Gelidium pusillum* was the dominant alga from the intertidal to the reef margin, this species has disappeared in the vicinity of the plume. Figure 22A & B show the general distribution of the dominant algal mats opposite the outfall in December 1972 and October 1974.

The October survey was conducted after Tanguisson No. 2 went on the line. Eight more of the species including four of the original blue green have disappeared. Only four of the 39 species observed prior to release of plant affluent now remain (a 90% reduction in the algal mat). *Microcoleus lyngbyaceus* now completely dominates the plume area, even in the spur and groove system of the reef margin. Of the above species that were considered somewhat resistant to effluent, only *Cladophoropsis membranacea* remains since Tanguisson No. 2 startup and it is restricted to the plume margins.

Due to heavy sedimentation from continued construction up through November 1972, very few algal species settled in the intake channel. The dominant species were *Jania capillacea*, *Gelidiella acerosa*, *Amphiroa fragilissima*, and *Galaxaura marginata* of the red algae and *Sargassum cristaefolium* of

Table 5. SPECIES LISTING OF MARINE BENTHIC ALGAE PRESENT ON REEF FLAT AND UPPER REEF MARGIN BEFORE (MARCH-JULY, 1970) AND AFTER (MAY-JULY, 1972 AND OCTOBER, 1974) THERMAL DISCHARGE.

SPECIES	BEFORE EFFLUENT	TANGUISSON NO. 1	TANGUISSON NOS. 1 & 2
CYANOPHYTA			
Calothrix confervicola (Roth) Ag.	X	X (abundant)	X (rare)
Entophysalis conferta (Kütz.) Dr. & D.	X	X	
Microcoleus lyngbyaceus (Kütz.) Crouan	X	X (abundant)	X (abundant)
Schizothrix calcicola (Ag.) Gomont	X	X	
Schizothrix mexicana Gomont	X	X	
Spirulina subsalsa Gomont	X	X	
CHLOROPHYTA			
Boergesenia forbesii (Harv.) Feldmann	X		
Boodlea composita (Harv.) Brand	X		
Bryopsis pennata Lamx.	X		
Caulerpa racemosa (Forssk.) J. Ag.	X		
Caulerpa taxifolia (Vahl) C. Ag.	X		
Chlorodesmis caespitosa J. Ag.	X		
Chlorodesmis fastigiata (C. Ag.) Ducker	X		
Codium geppii O. C. Schmidt	X		
Dictyosphaeria cavernosa (Forssk.) Boerg.	X		
Dictyosphaeria versluysii W. v. Bosse	X		
Enteromorpha intestinalis (L.) Link	X (rare)		
Halimeda opuntia (L.) Lamx.	X	X (abundant)	
Valonia fastigiata Harvey	x		
Cladophoropsis membranacea (Ag.) Boerg.	X	X	X

Table 5. (CONTINUED)

SPECIES	BEFORE EFFLUENT	TANGUISSON NO. 1	TANGUISSON NOS. 1 & 2
PHAEOPHYTA			
Dictyota bartayresii Lamx.	X		
Dictyota divaricata Lamx.	X	X (matted)	
Feldmannia indica (Sondar) Womersley & Bailey	X (rare)		
Hydroclathrus clathratus (Ag.) Howe	X		
Padina tenuis Bory	X	X (Only vaughiella stage)	
Rosenvingea intricata (J. Ag.) Boerg.	X		
Sargassum cristaefolium J. Ag.	X (rare)		
Turbinaria ornata (Turn.) J. Ag.	X		
RHODOPHYTA			
Actinotrichia fragilis (Forssk.) Boerg.	X		
Amphiroa fragilissima (L.) Lamx.	X	X	
Cheilosporum multifidium (Kütz.) Manza	X		
Gelidiella acerosa (Forssk.) Feldmann & Hamel	X		
Gelidium pusillum Setchell	X		
Gracilaria salicornia (Mert.) Grev.	X		
Hypnea pannosa J. Ag.	X		
Jania capillacea Harvey	X		
Laurencia obtusa (Huds.) Lamx.	X		
Mastophora lamourouxii (Decaisne) Harv.	X		
Polysiphonia scopulorum Harvey	X	X	X
	39	12	4

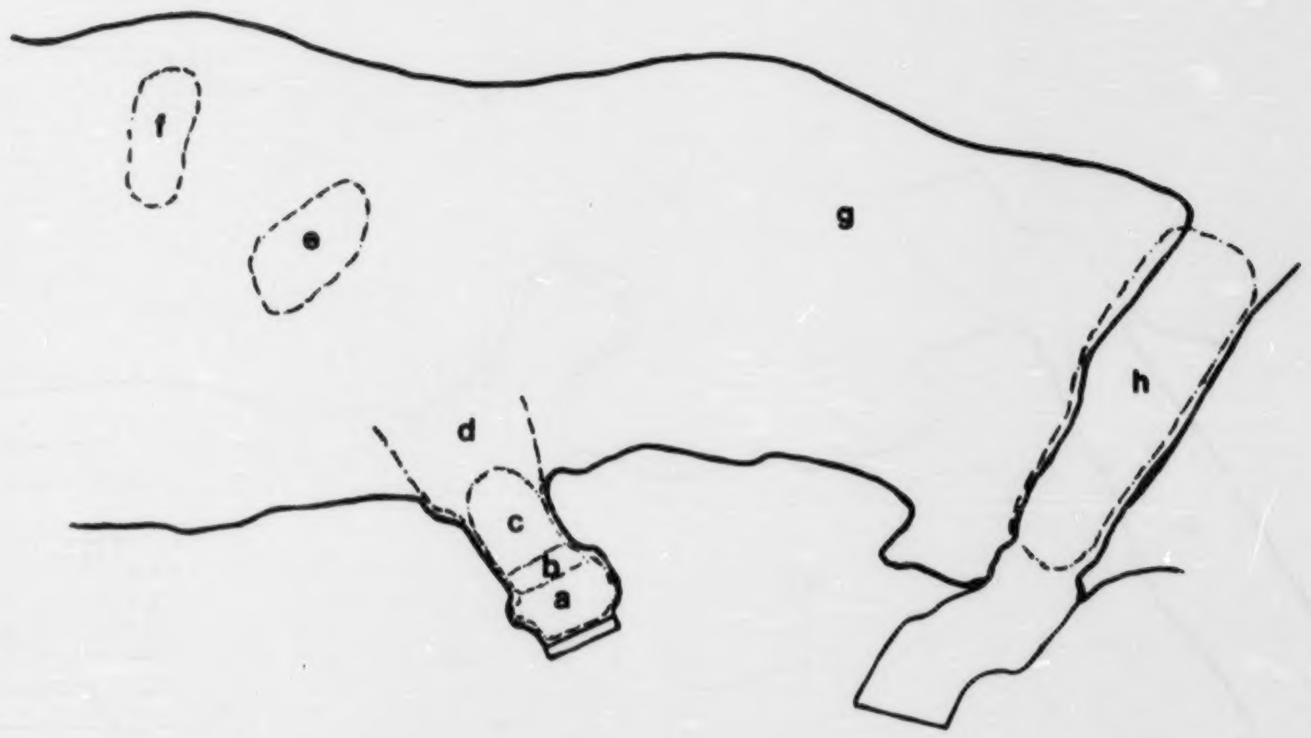

Figure 22 A. Algal community after thermal discharge.

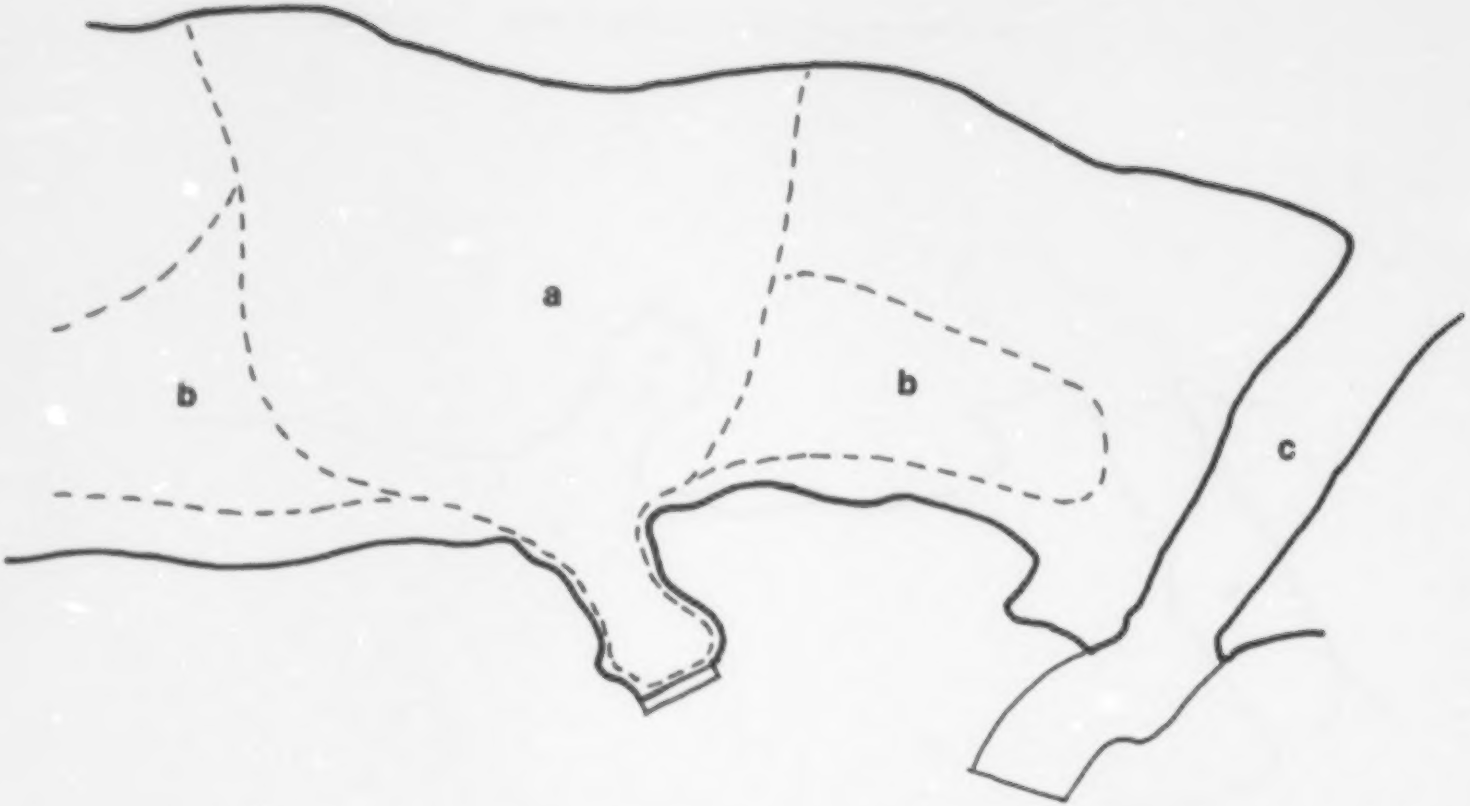

Figure 22 B. Algal community after thermal discharge of Tanguisson No. 1 and 2.

the brown (Fig. 22A). Blue green algae were still present in the channel but were no longer dominant as they had been after the initial channel construction. Figure 22B shows that three of the intake channel species have disappeared and seven new species added since startup of Tanguisson No. 2. G. marginatus remains the domant alga in the channel.

FISHES

The effect of thermal effluent on fishes was examined primarily in the reef flat, reef margin and reef front zones. The submarine terrace and other seaward zone fish communities were not influenced significantly by effluent because of thermal stratification.

Timed random counts were made in each zone. These counts enumerate only the number of species and not the individuals of each species. Several trial counts were made and plotted as number of species versus time (60 minutes). These species/time curves showed that 90% of the ubiquitous species present were accounted for in the first 20 minutes of counting. Therefore this time was selected for the random counts. No attempt was made to observe the cryptic species. Our objective was only to show obvious differences in species richness before and after the injection of plant effluent.

Twenty minute random counts were made in 1971 prior to the beginning of plant operations and were repeated in 1972 after plant operation started. These data are shown in Table 6 for each of the pertinent zones.

The reef flat zone has a characteristic but somewhat depauperate fish community (Table 6). When Tanguisson No. 1 began operating, all members (32 species) of this reef flat community, including territorial species, disappeared from within the limits of the thermal plume. Other workers (Clarke et al[9] and Chesher[10]) have reported aggregations of fish species around thermal outfalls. This is not the case at Tanguisson. Here, the stilling well was devoid of fishes as was the adjacent reef flat from intertidal to reef margin. Large numbers of fishes do appear along the margin but in less than normal concentrations for this habitat. Typical reef flat species begin to reappear in a southerly direction along the reef flat. The reef flat community north of the intake channel is a part of the NCS swimming lagoon and has a past history of disturbance from dredging activies. The area is not influenced by effluent discharge and is not considered further here.

During the period from November 2 to November 20, 1972, the power plant personnel ran out of chlorine which forced a halt in treatment for condensor fouling organisms. (Personal Communication, F. Melder). During this period, common reef flat species began to immediately recolonize the reef flat, even within the "thermal effluent". Eleven species were recorded in the area (Table 6). The stilling well also became populated with fishes in spite of hot water and considerable turbulence. A total of nine species were observed including large schools of *Siganus spinus* and *Mulloidichthys samoensis* (Table 6). These species and those of the adjacent reef flat remained and even increased in numbers until November 20 when a new shipment of chlorine was received by the plant. Chlorine treatments were started again on this date. By the afternoon of the next day, all species of fishes had disappeared from the stilling well and the area under the effluent plume over the reef flat was devoid of fishes. No change was noted at the reef margin.

The reef margin and upper front zones have a diverse fish community associated with the live corals that normally occur along the reef margin and front. A twenty minute random count was made in the upper reef front and margin in November 1971 just prior to the first injection of hot water from Tanguisson No. 1 (Table 6). At this time 63 species were observed. Another count was made in February 1972 after injection of effluent began and corals began dying. This count yielded a 44% reduction from 63 to 35 species (Table 6). Three subsequent counts made in the summer of 1974 showed a mean count of 37 species. Hence, there was no significant increase in the number of species some two and one half years later. The last counts were made with both generating units in operation but unlike the coral (see below) and algal observations, there were no additional reductions in the fish population. The same basic species composition also remained.

Three 20 minute counts were also made in 1974 adjacent to the power plant and over the lower reef front where the effluent is normally stratified. The mean of these three counts was 69 species or some 46% increase just seaward of the surf zone where mixing of the hot water occurs. Another count made north of the outfall site outside of the influence of thermal discharge, showed 77 species. There seems to be little question that many of the species normally found in the reef margin and upper front are avoiding the area, most likely because of the hot water. No chlorine was being used when the 1974 counts were made. Even those species that are found within hot water dominated areas tend to wander continuously in and out of the surge channels. A few territorial species are found in cooler water layers at the bottom of the deepest surge channels.

Although an increase in number of species was noted in the lower reef front under the stratified effluent, the fish community still did not appear normal. We suspected that the combination of *Acanthaster* destruction of corals in the lower reef front and the effluent in the margin and upper front might adversely influence the fish community. Four additional 20 minute random counts were conducted in a similar reef environment near Cocos Island (Fig. 1) where neither *Acanthaster* damage nor thermal effluent existed. The mean of the four counts yielded 81 species which does suggest

Table 6. VISUAL FISH COUNTS (1971-1972). Contrast is shown in each zone, before and after the release of plant effluent. In addition, a comparison is made during and after the November 2 to November 20, 1972 period when the power plant was not using chlorine.

		REEF FLAT			STILLING WELL			REEF MARGIN	
SPECIES	Intake Channel (1971)	Before Effluent (1971)	After Effluent (1972)	No Cl - (1972)	With Cl - (1972)	No Cl - (1972)	With Cl - (1972)	Before Effluent (1971)	After Effluent (1972)
Acanthuridae									
Acanthurus lineatus	0	+	0	+	0	0	0	+	+
A. nigroris	+	0	0	0	0	0	0	+	0
A. nigrofuscus	0	0	0	0	0	+	0	+	+
A. triostegus	+	+	0	+	0	+	0	+	+
A. xanthopterus	0	+	0	0	0	0	0	+	+
A. glaucoparieus	0	0	0	0	0	0	0	+	0
A. olivaceus	0	0	0	0	0	0	0	+	0
A. guttatus	0	0	0	0	0	0	0	0	+
Ctenochaetus striatus	0	0	0	0	0	0	0	0	+
Naso lituratus	0	+	0	0	0	0	0	+	+
N. unicornis	0	0	0	0	0	+	0	0	+
Apogonidae									
Apogon sp.	0	+	0	0	0	0	0	+	0
Balistidae									
Rhinecanthus rectangularis	0	+	0	0	0	0	0	+	+
Balistapus undulatus	0	+	0	0	0	0	0	0	+
Blenniidae									
Entomacrodus sp.	0	0	0	0	0	0	0	+	0
Istiblennius coronatus	0	0	0	0	0	0	0	+	+
I. cyanostigma	0	+	0	+	0	+	0	0	0
Cirripectes variolosus	0	0	0	0	0	0	0	+	0

Table 6 (Continued)

SPECIES		REEF FLAT			STILLING WELL			REEF MARGIN	
	Intake Channel (1971)	Before Effluent (1971)	After Effluent (1972)	No Cl - (1972)	With CL - (1972)	No CL - (1972)	With CL - (1972)	Before Effluent (1971)	After Effluent (1972)
Runula tapeinosoma	0	0	0	0	0	0	0	+	0
Rhabdoblennius snowi	0	+	0	0	0	0	0	0	0
Praealticus natalis	0	+	0	0	0	0	0	0	0
Salarias fasciatus	0	+	0	0	0	0	0	0	0
Canthigasteridae									
Canthigaster janthinopterus	0	0	0	0	0	0	0	+	0
C. amboinensis	0	0	0	0	0	0	0	+	0
C. solandri	0	+	0	0	0	0	0	0	0
C. bennetti	0	+	0	0	0	0	0	0	0
Carangidae									
Caranx sp. 1 (juveniles)	0	+	0	0	0	0	0	0	0
Caranx sp. 2	0	0	0	0	0	0	0	0	0
Chaetodontidae									
Chaetodon auriga	0	+	0	0	0	0	0	+	+
C. citrinellus	0	+	0	0	0	0	0	+	+
C. lunula	0	+	0	+	0	+	0	+	+
C. ornatissimus	0	0	0	0	0	0	0	+	+
C. ephippium	0	0	0	0	0	0	0	+	0
C. punctato-fasciatus	0	0	0	0	0	0	0	+	0
C. falcula	0	0	0	0	0	0	0	+	0
C. unimaculatus	0	0	0	0	0	0	0	+	0
C. quadrimaculatus	0	0	0	0	0	0	0	0	0
Heniochus permutatus	0	0	0	0	0	0	0	0	0
Forcipiger flavissimus	0	0	0	0	0	0	0	+	0
Pomacanthus imperator (juv.)	0	0	0	0	0	0	0	+	0

Table 6 (Continued)

	REEF FLAT				STILLING WELL			REEF MARGIN	
SPECIES	Intake Channel (1971)	Before Effluent (1971)	After Effluent (1972)	No Cl -(1972)	With CL - 1972)	No CL - (1972)	With CL - (1972)	Before Effluent (1971)	After Effluent (1972)
Cirrhitidae									
Cirrhitus pinnulatus	0	0	0	0	0	0	0	+	+
Paracirrhites forsteri	0	0	0	0	0	0	0	+	0
P. hemistictus	0	0	0	0	0	0	0	0	0
P. arcatus	0	0	0	0	0	0	0	+	0
Neocirrhites armatus	0	0	0	0	0	0	0	+	0
Eleotridae									
Eviota smaragdus	0	+	0	0	0	0	0	0	0
E. zonura	0	+	0	0	0	0	0	0	0
Ptereleotris tricolor	0	0	0	0	0	0	0	+	0
Fistulariidae									
Fistularia petimba	0	0	0	+	0	0	0	0	0
Gobiidae									
Bathygobius fuscus	0	+	0	0	0	0	0	0	0
Kelloggella cardinalis	0	+	0	0	0	0	0	0	0
Labridae									
Halichoeres hortulanus	0	+	0	0	0	0	0	+	+
H. marginatus	+	0	0	0	0	0	0	+	+
H. margaritaceus	0	+	0	+	0	0	0	+	+
H. trimaculatus	+	+	0	0	0	0	0	0	0
Labrichthys cyanotaenia	0	0	0	0	0	0	0	+	0
Cheilinus fasciatus	0	0	0	0	0	0	0	+	0
Macropharyngodon meleagris	0	0	0	0	0	0	0	0	+

Table 6 (Continued)

SPECIES	REEF FLAT				STILLING WELL			REEF MARGIN	
	Intake Channel (1971)	Before Effluent (1971)	After Effluent (1972)	No Cl - (1972)	With CL - (1972)	No CL - (1972)	With CL - (1972)	Before Effluent (1971)	After Effluent (1972)
M. pardalis	0	0	0	0	0	0	0	+	0
Stethojulis axillaris	+	+	0	0	0	0	0	+	+
S. linearis	0	0	0	0	0	0	0	+	0
Hemigymnus melapterus	0	0	0	0	0	0	0	0	+
Thalassoma umbrostigma	0	0	0	0	0	0	0	0	+
T. quinquevittata	0	0	0	0	0	0	0	+	+
T. purpureum	0	0	0	0	0	0	0	+	0
T. fuscum	0	0	0	0	0	0	0	+	0
Labroides dimidiatus	0	0	0	0	0	0	0	+	0
Lutjanidae									
Scolopsis cancellatus	0	+	0	0	0	0	0	+	0
Lutjanus monostigmus	+	0	0	0	0	0	0	0	0
Monacanthidae									
Amanses sandwichiensis	0	0	0	0	0	0	0	+	0
Mugilidae									
Chelon vaigiensis	0	+	0	0	0	0	0	0	+
Mullidae									
Parupeneus trifasciatus	0	0	0	0	0	0	0	+	+
P. bifasciatus	0	0	0	0	0	0	0	+	0
Mulloidichthys samoensis	+	0	0	0	0	+	0	0	0
Ostraciontidae									
Ostracion meleagris	0	0	0	0	0	0	0	+	0

Table 6 (Continued)

SPECIES	REEF FLAT				STILLING WELL			REEF MARGIN	
	Intake Channel (1971)	Before Effluent (1971)	After Effluent (1972)	No Cl - (1972)	With Cl - (1972)	No. CL - (1972)	With CL - (1972)	Before Effluent (1971)	After Effluent (1972)
Pomacentridae									
Abudefduf dicki	0	0	0	0	0	0	0	+	+
A. imparipinnis	0	0	0	0	0	0	0	+	0
A. amabilis	+	+	0	+	0	0	0	+	+
A. leucopomus	0	+	0	+	0	0	0	+	+
A. biocellatus	0	0	0	0	0	0	0	+	0
A. septemfasciatus	+	+	0	+	0	0	0	+	+
A. saxatilis	0	0	0	0	0	0	0	0	+
A. leucozona	0	+	0	0	0	+	0	0	0
A. glaucus	+	+	0	+	0	+	0	0	0
Pomacentrus albofasciatus	+	+	0	0	0	0	0	+	+
P. jenkinsi	0	0	0	0	0	0	0	+	+
P. vaiuli	0	0	0	0	0	0	0	+	0
Scaridae									
Calotomus spinidens	0	0	0	0	0	0	0	+	0
Scarus sp.	0	0	0	0	0	0	0	+	0
S. sordidus	0	+	0	0	0	0	0	+	0
Serranidae									
Cephalopholis urodelus	0	0	0	0	0	0	0	+	0
Teuthididae									
Siganus spinus	+	0	0	+	0	+	0	+	+
Zanclidae									
Zanclus cornutus	0	0	0	0	0	0	0	+	+
Totals	12	32	0	11	0	9	0	63	35

that a combination of factors may be operating.

Fishes common in the intake channel before Tanguisson No. 1 began operating in 1971 are shown in Table 6. Except for transients, most of the species listed are common in channel structures such as this. The intake channel fish community had not yet reached its full potential in terms of succession. This process was considerably delayed by the fact that intake construction for Tanguisson No. 2 had kept the channel turbid until November 1972. One twenty minute random count made in the intake channel in the summer of 1974 yielded 57 species, a clear sign that succession was far more advanced (a 79% increase from 12 species).

Although entrained organisms were not a specific objective of this study, one observation was made that warrants mention. From April to June and again in October, huge schools of larval mañahac, *Siganus spinus*, move from the pelagic environment into the inshore waters of Guam. These larvae metamorphose into juveniles and enormous schools are found concentrated on reef flats. The people of the island traditionally harvest the juvenile fishes in great quantity for consumption. During the 1972 manahac run, large schools of the species were found in the intake channel of Tanguisson No. 1. Near the end of the period when plant personnel had suspended chlorination treatments, the water boxes of the plant were opened and condenser tubes inspected for possible fouling. Hundreds of specimens of mañahac were found plastered to the interspaces between the condenser tubes and on the floor of the water boxes. It is quite likely that many thousands, of the animals are entrained in the circulating water and killed by either mechanical damage or temperature increase. This high mortality is probably a seasonal phenomenon involving this species primarily. It is doubtful that normal channel inhabitants are drawn into the circulating system. No attempt was made to study the possible destruction of larvae or juveniles of other fish species passing through the plant.

CORALS

The fringing reefs located along the northwest coast of Guam (Fig. 1) supported a rich and diverse coral community prior to the *Acanthaster planci* infestation of this region (Tracey et al[1] and Randall[12]). Randall[12] describes the reef complex at Tumon Bay in detail. The rich coral zones at Tumon Bay and nearby Tanguisson Point (Fig. 1) became infested with *A. planci* in 1967 and 1968 (Randall[12, 14, 18] and Chesher[15]). Intensive predation left the seaward slope, submarine terrace, and the outer part of the reef front zones with less than 10 percent of the reef surface covered with living corals. The reef margin and inner part of the reef front were not heavily infested by starfish, because of wave agitation in these zones, and much of the coral community survived. Section X of this report describes the reef complex at Tanguisson Point in detail after the starfish predation of 1967 and 1968.

Prior to plant operations, it was predicted that effluent from Tanguisson No. 1 might kill part of the surviving coral reef community existing on the reef margin and reef front zones (Jones et al[13]). The prediction was based on the fact that the coral reef community, in the above reef zones, has developed in and is adjusted to the small annual temperature changes that occur in this part of the Pacific Ocean. Moreover, thermal stress on reef corals is probably greater when applied continuously, as is the case with power plant effluent, than when applied diurnally from insolation or seasonal changes.

Final testing of Tanguisson No. 1 began in December, 1971 and the plant became fully operational in January, 1972. Effluent was discharged at the outfall site onto the inner part of the reef flat platform (Fig. 23). The movement, and factors affecting the movement of this effluent toward the reef margin are discussed in the previous section on currents and is shown in Figures 6 and 21.

During the testing period, the first observation of a "coral-kill" in the outfall region was made (on December 27, 1971). At that time a two-man team was recovering thermographs from the reef margin on Transect B and noticed that numerous corals were of a pale or bleached-white color (Fig. 24-26). The results of a survey showed that the zone in which freshly killed corals were found was roughly limited to the region outlined in Figure 23. The boundaries of the coral-kill zone were not sharply defined except for a shoreward section located along the inner reef margin where the effluent first makes contact with living corals (Fig. 23d). In a peripheral zone (Fig. 23f) the corals killed were usually limited to the upper surfaces of submarine buttresses and the upper margins of the surge channels (Fig. 24 and 27). The coral species killed in the peripheral zone were presumably those with less thermal tolerance (Table 7). As the warmer area of the coral-kill zone (Fig. 23e, core zone) was approached, the density of bleached and freshly killed corals increased along with the number of species affected. In the core area itself the coral-kill was not limited to the upper regions of reef topographic features. It extended downward as well, along the walls of surge channels, submarine channels, and the floors of these two features (Figs. 25 and 27). Although heated outfall water has a tendency to float on the surface of the cooler ambient temperature seawater, data presented in the previous section on temperature indicates that wave and surf action mixes the effluent at the reef margin and inner part of the reef front zones (Fig. 27). This mixing action extends the vertical range in which corals are killed. Seaward of the surf zone the warmer water becomes stratified and is generally restricted to the upper one meter layer of water. It has little effect on living corals, since the water depth there is usually greater than one meter, except where the upper parts of corals knobs and knolls extend up into this one meter layer (Fig. 27).

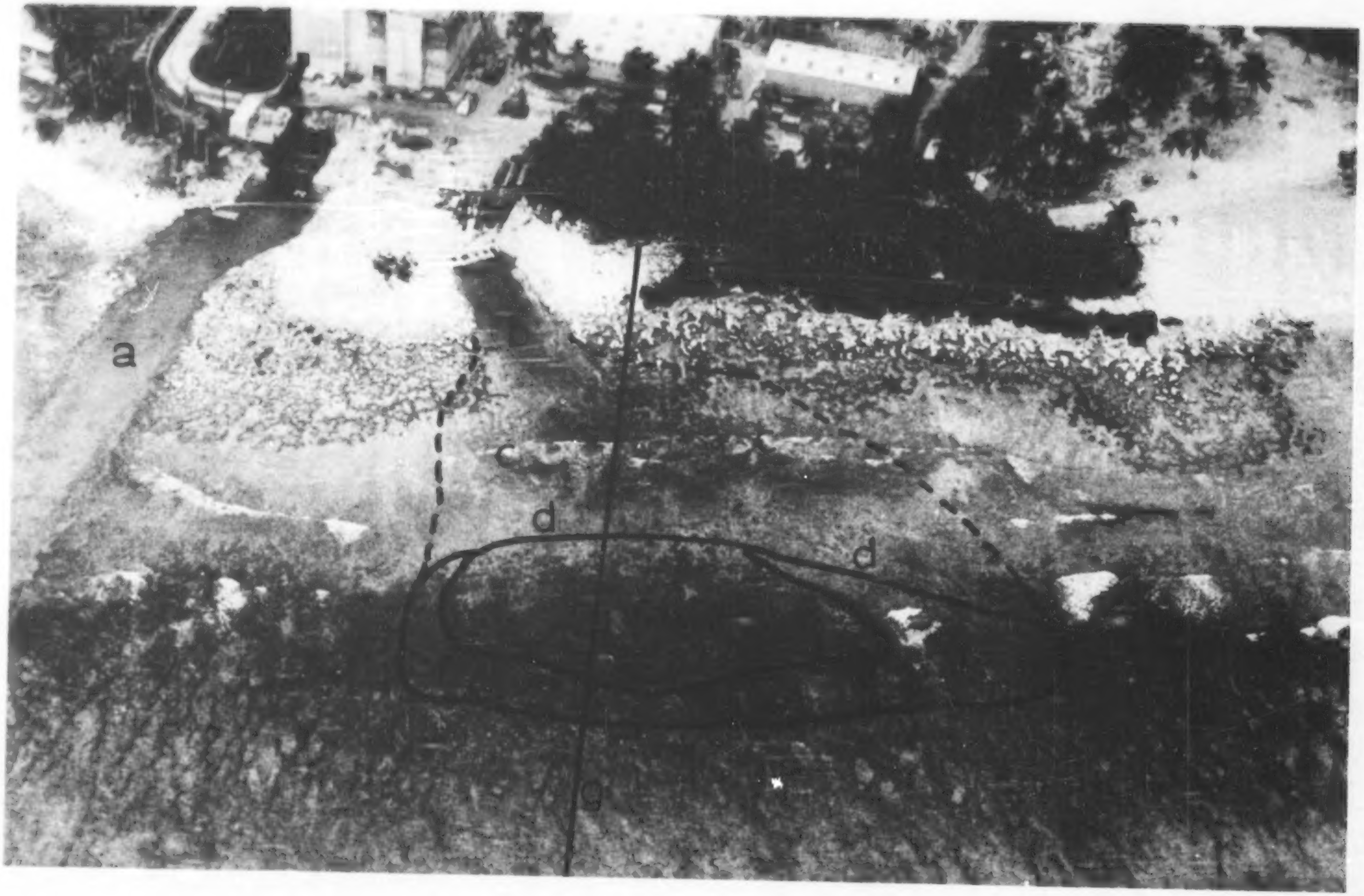

Figure 23 Limits of coral kill as of December, 1972

Table 7 was based on observations of the number of bleached corals, and surviving corals from the central core of the coral-kill zone outward to the peripheral region. Corals of the genera *Acropora*, *Montipora*, and *Pocillopora* were found to be the least tolerant to effluent. The only coral species consistently surviving in the central core zone were *Goniastrea retiformis*, *Psammocora* (P.) *haimeana*, *Favites abdita*, *Cyphastrea chalcidicum* and a small, cryptic, encrusting *Porites* species.

Close observation revealed that not all the pale colored or bleached corals were dead. Some were still living, with polyps and tentacles extended. Others were partly killed with the uppermost, bleached part of the corallum dead and the basal-lateral parts bleached and living. Numerous authors have shown that corals under stress begin to expel their zooxanthellae. The loss of this brown colored algal symbiont leaves the coral either a bleached white color, or more commonly, reveals the presence of other pale colored pigments normally masked by the zooexanthellae (Fig. 25). Under continued stress the corals lose more zooexanthellae and pigments, becoming white and colorless (Fig. 25). If stress is uninterrupted, death of polyps and disintegration of the coenosarc follows. This is in basic agreement with observations made at the Kahe Pt. generating facility in Hawaii by Jokiel and Coles[11]. Usually, the first organisms to recolonize this new surface are various species of blue-green algae (Fig. 26).

The reef margin and reef front zones have been monitored continuously since the initiation of field work and the establishment of permanent Transects A, B, and C in 1970 (Fig. 3). Transect B bisects the main part of the outfall plume, where it crosses the reef flat zone and enters the reef margin and reef front zones (Fig. 23g). Quadrat stations on Transect B (reef flat, reef margin, and reef front zones) were analyzed for percent of living coral covering the reef surface and species composition before the coral-kill during April 1970, after the coral-kill in May 1972 and again in January 1973. Table 8 summarizes the results of these transect studies by quadrat stations in the region of the coral-kill zone.

Small seasonal changes in seawater temperatures, changes in wind and swell direction, and continued stress from the effluent plume have subsequently changed the boundaries of the original coral-kill zone of December 1971 (Fig. 23) to that shown in Figure 28 for January 1973. The initial region affected (peripheral zone) in Figure 23 was 118 m by 32 m. The core zone was 80 m in length and 26 m in width. The total area affected was 3,776 m^2 and the core zone was 2,080 m^2. The affected region shown in Figure 28 was drawn from field data collected one year later. The damaged area increased to a total of 186 m by 55 m, and the core zone increased to 108 by 40 m. The area affected increased to about 10,000 m^2 overall and 4,320 m^2 for the core region.

Table 7. RELATIVE RESISTANCE OF CORALS TO THE EFFLUENT AT TANGUISSON POINT. Loss of pigment is used as an index.

Name of Coral	Normal	Pale	Bleached	Dead
Stylocoeniella armata		X		
Psammocora nierstraszi	X			
Psammocora (P.) haimeana	X			
Stylophora mordax			X	
Pocillopora eydouxi			X	
Pocillopora meandrina				X
Pocillopora setchelli				X
Pocillopora verrucosa				X
Acropora abrotanoides				X
Acropora studeri				X
Acropora humilis			X	
Acropora hystix				X
Acropora murrayensis				X
Acropora nana				X
Acropora nasuta				X
Acropora ocellata				X
Acropora palmerae				X
Acropora smithi				X
Acropora surculosa			X	
Acropora syringodes				X
Acropora valida				X
Acropora wardii				X
Montipora concicula			X	
Montipora elschneri		X		
Montipora foveolata			X	
Montipora hoffmeisteri			X	
Montipora verrilli			X	
Montipora verrucosa				X
Montipora sp. 1				X
Montipora sp. 2			X	
Pavona clavus			X	
Pavona varians			X	
Coscinaraea columna	X			
Porites australiensis		X		
Porites lobata		X		
Porites lutea		X		
Porites sp. 1	X			
Favia favus		X		
Favia pallida		X		
Favia speciosa		X		

Table 7. (Continued)

Name of Coral	Normal	Pale	Bleached	Dead
Favia stelligera		X		
Favia rotumana		X		
Favites abdita	X			
Favites complanata		X		
Favites favosa		X		
Favites flexuosa	X			
Plesiastrea versipora		X		
Goniastrea retiformis	X			
Goniastrea parvistella		X		
Platygyra rustica			X	
Platygyra sinensis			X	
Leptoria gracilis		X		
Leptoria phrygia		X		
Hydnophora microconos	X			
Leptastrea purpurea		X		
Leptastrea transversa		X		
Cyphastrea chalcidicum	X			
Galaxea hexagonalis		X		
Lobophyllia costata			X	
Acanthastrea echinata	X			
Heliopora coerulea			X	
Millepora dichotoma			X	
Millepora exaesa			X	
Millepora platyphylla			X	
TOTAL SPECIES	10	19	18	17

Table 8. A COMPARISON OF THE PERCENTAGE OF LIVING CORAL COVERING THE REEF SURFACE AND THE NUMBER OF CORAL GENERA AND SPECIES PRESENT AT TANGUISSON POINT. Transect B, 1970-1974. (Stations 14-16 were severly damaged by Acanthaster planci in 1968).

Transect Quadrat Station (x10-meters from shore)	Reef Zone	Percent of Cover				Number of Genera and Species			
		1970	1972	1973	1974	1970	1972	1973	1974
8	Reef Flat	0	0	0	0	0-0	0-0	0-0	0-0
9	Reef Flat	0	0	0	0	0-0	0-0	0-0	0-0
10	Reef Flat	1	0	0	0	2-2	0-0	0-0	0-0
11	Reef Margin	1	2	0	0	7-12	1-1	0-0	0-0
12	Reef Margin	56	1	0	0	10-14	6-10	0-0	0-0
13	Reef Front	83	37	4	0	9-15	8-16	2-4	0-0
14	Reef Front	41	38	12	4	9-18	7-14	2-4	3-3
15	Reef Front	64	19	18	20	8-10	9-12	9-10	9-12
16	Reef Front	21	53	49	48	11-13	10-15	10-16	9-15

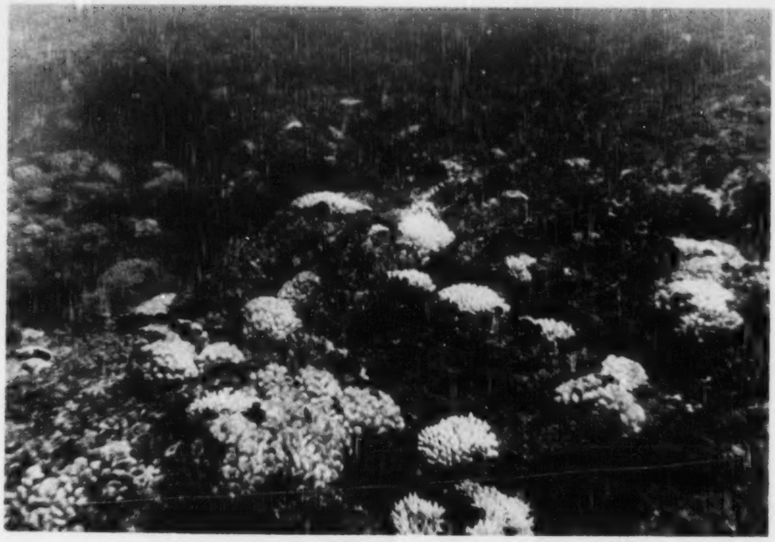

Figure 24 Coral kill on upper surface of a reef margin buttress

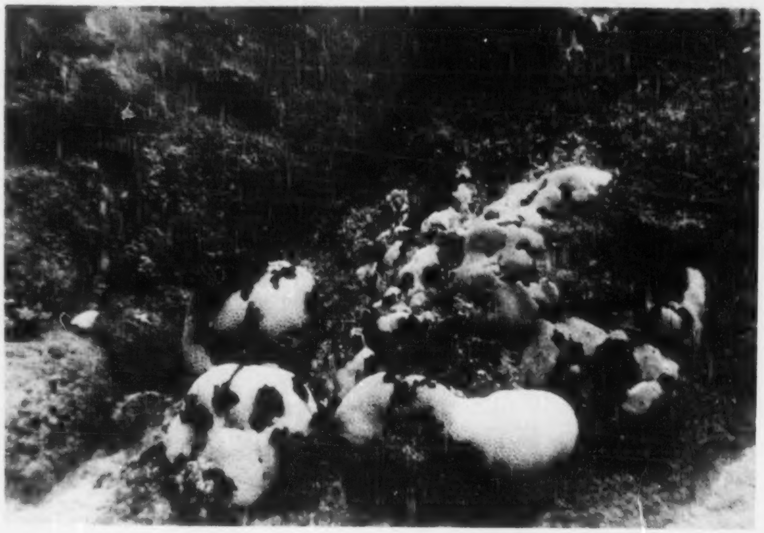

Figure 25 Pale and bleached corals on the walls and floor of a reef margin surge channel

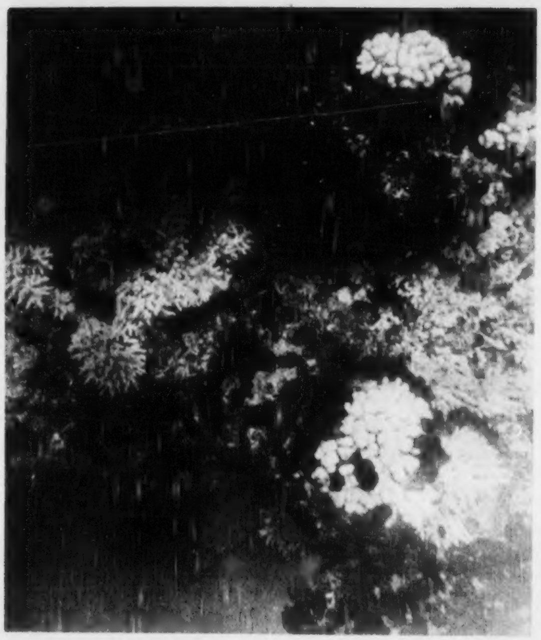

Figure 26 Dead coral and coralline algae surface being recolonized by blue green algae

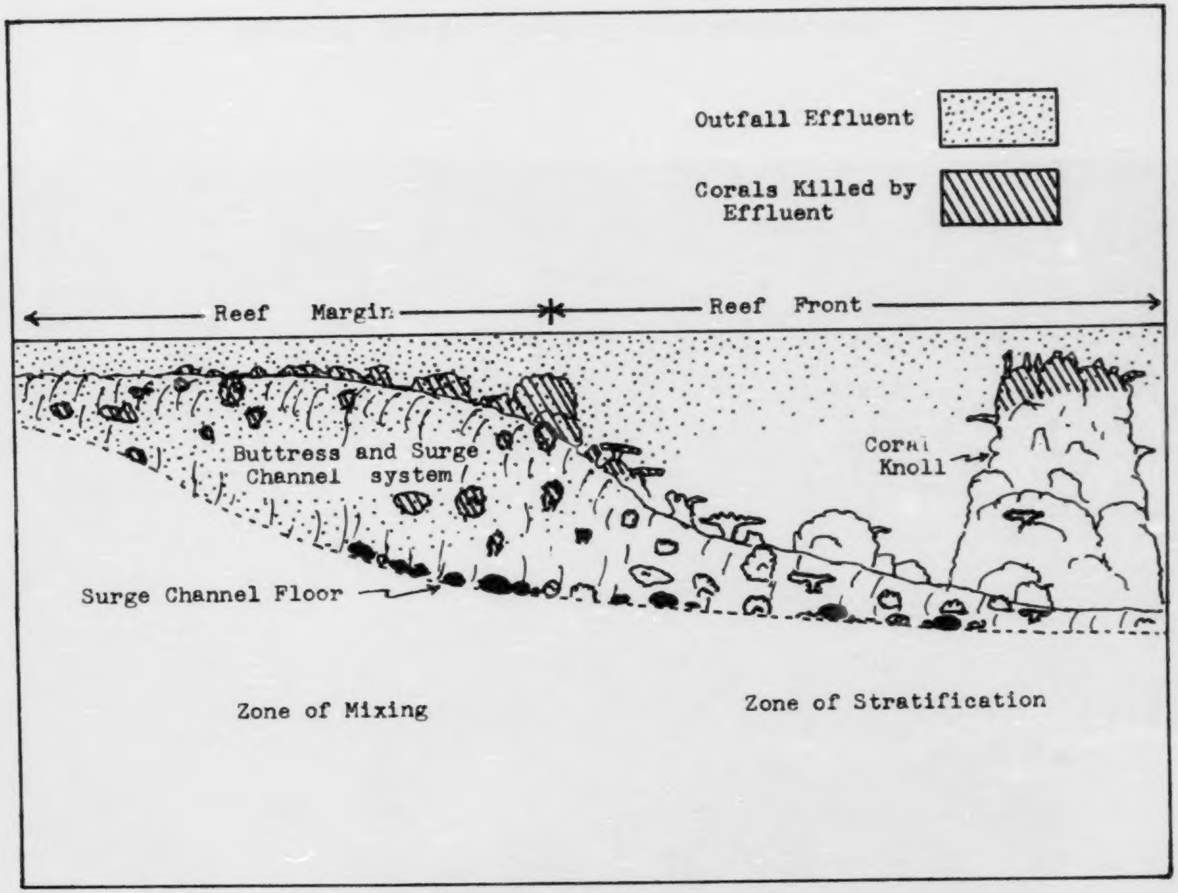
Outfall Effluent
Corals Killed by Effluent
Reef Margin
Reef Front
Buttress and Surge Channel system
Coral Knoll
Surge Channel Floor
Zone of Mixing
Zone of Stratification

Figure 27 Vertical profile through the reef margin and reef front zones

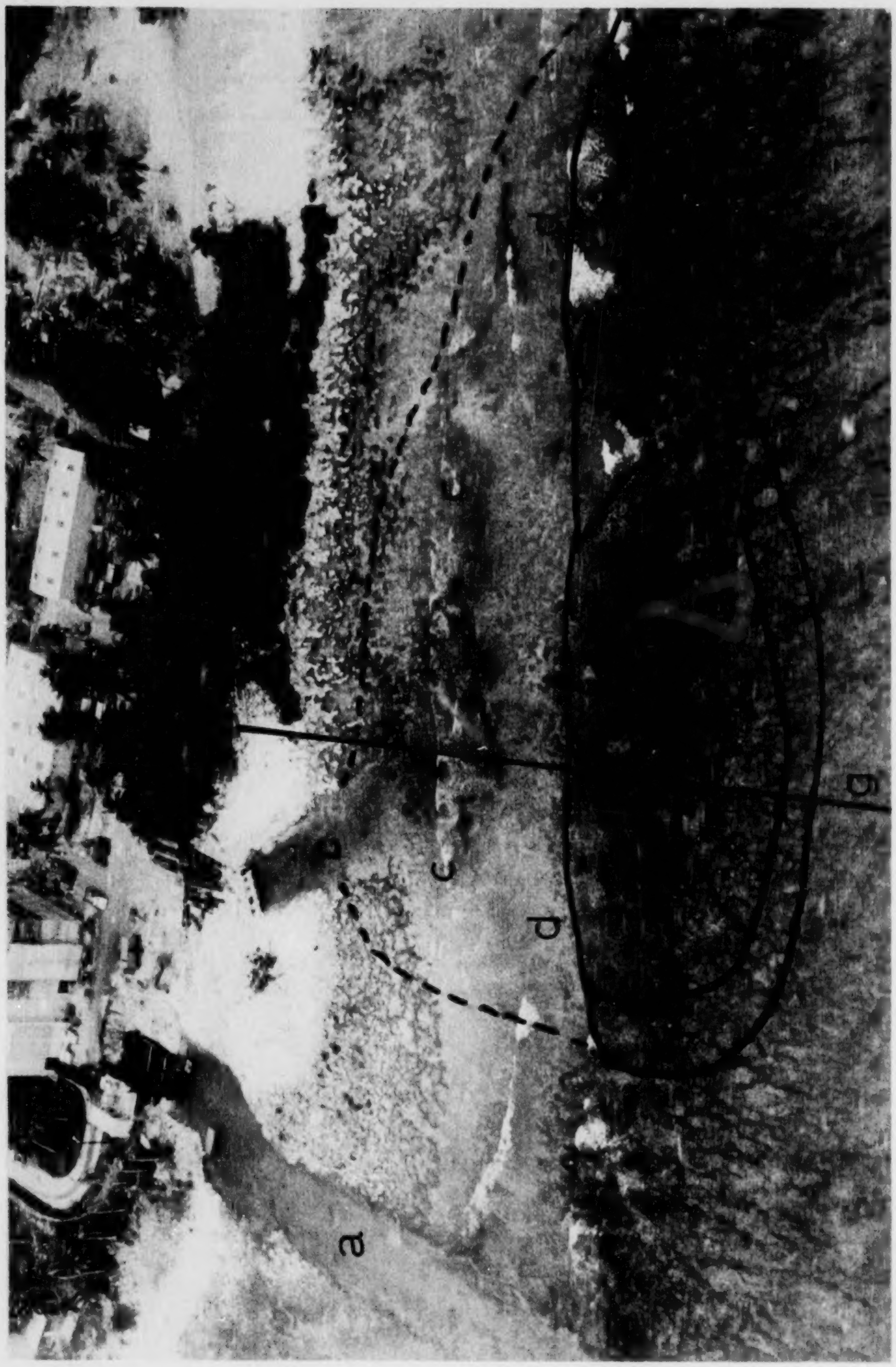

Figure 28 Limits of coral kill as of January, 1973

The damage reported above was caused primarily by the discharge of effluent from Tanguisson Unit No. 1. Now that Tanguisson Unit No. 2 is in operation, along with Unit No. 1, the volume discharge has doubled over the adjacent fringing reef community. This increased discharge was expected to affect a greater area of the reef community than that which was previously affected with only one generating unit in operation. The extent of the coral-kill area (core and peripheral zones) was again assessed in October, 1974, with both power plant units in operation.

Preliminary investigations revealed the presence of a peripheral zone of pale or bleached-colored and recently killed corals along the fringing reef from the intake channel southward to Transect C (Fig. 29). The width of the affected reef area was again determined by measuring the seaward extent of the core and peripheral zones from the inner reef margin zone along a series of transect lines. The outer boundaries of the core and peripheral zones are roughly outlined in Figure 29. In general, the core zone has its maximum width at Transect B. From there, it extends laterally along the reef margin northward about halfway to the intake channel and southward to the cavernous surge channels shown in Figure 5 (VI). Maximum width and length of the core zone was found to be 40 m by 400 m with an affected area in which over 90 percent of the corals have been killed. Maximum width and length of the peripheral zone is about 55 m by 600 m. Since the last measurements of the coral-kill zones were made in January, 1973 (Fig. 28), the core zone area has increased from 4,320m^2 to 10,300m^2 and the peripheral zone from 10,000 m^2 to 20,000 m^2 (Fig. 29).

The area of the core and peripheral zones has at least doubled since the number of power plant units doubled. This increase has been due mainly to a lateral extension of the affected area both north and south of the outfall at Transect B. There was no increase in maximum width because the warm water becomes stratified seaward of the surf zone (Fig. 27). Lateral extension of the affected area has been due to the greater volume of the thermal effluent present, which is transported more or less parallel to the reef margin and upper reef front zones in the manner described for this region in Section V (Currents). Jokiel and Coles[11] report a doubling of affected reef areas at Kahe Pt. with a one-third increase in generating capacity and waste heat discharge rate.

Transect studies conducted during 1974 show a further reduction in the percentage of substrate covered by living corals at Stations B-13 and 14 (130 m and 140 m from shoreline), but normal values for this parameter were found in the deeper water from Station B-15 (150 m) seaward (Table 8).

The relative resistance of various coral species to thermal effluent is,

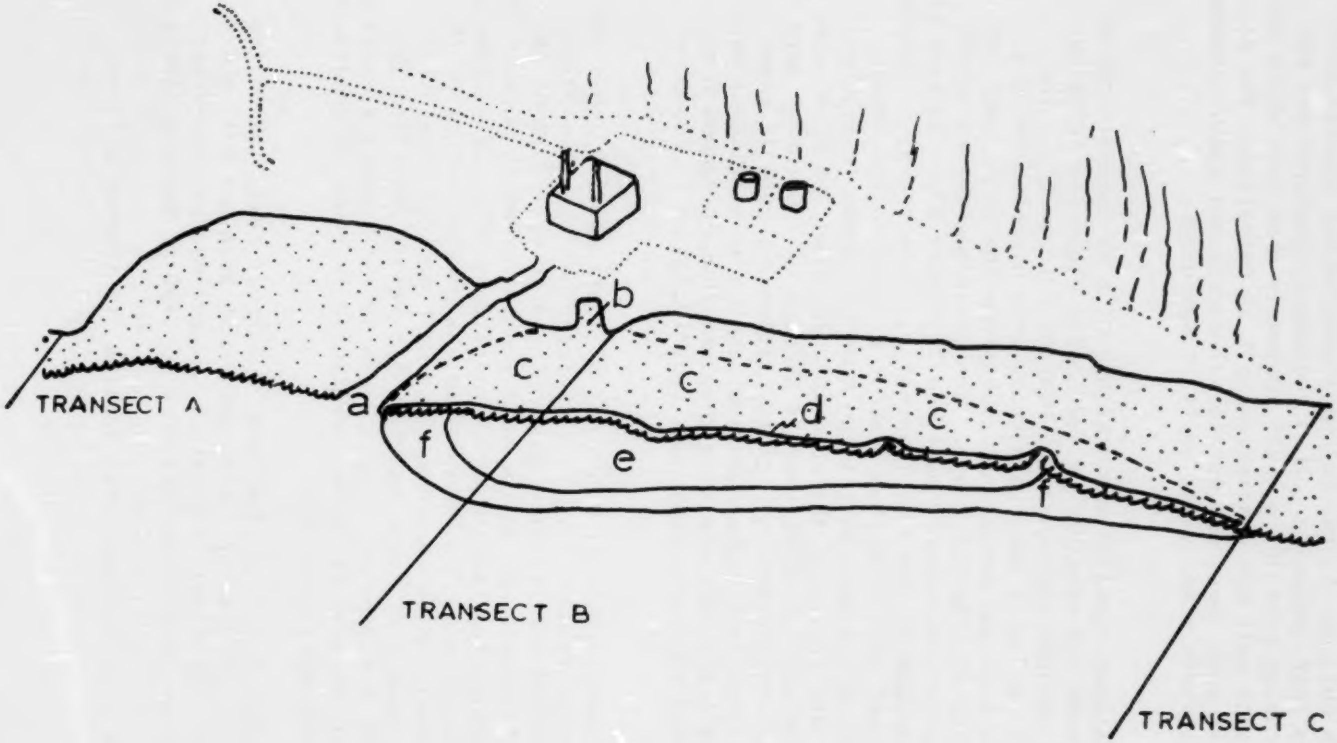
a
b
c
c
c
d
e
f
f
TRANSECT A
TRANSECT B
TRANSECT C

Figure 29 Limits of coral kill as of October, 1974

for the most part, the same as that described during the earlier observations (Table 7). Regardless of when observations were made in the peripheral zone, one could always find living pale or bleached corals in which there had been a loss, to some degree, of zooxanthellae and other pigments. Many of the corals in this zone are intermittently exposed to elevated temperatures, depending upon the temperature and volume discharge of the plant effluent, local weather and tidal conditions, as well as seasonal induced variations. Corals in the peripheral zone are thus subjected to sublethal thermal stress because of the constantly changing thermal plume dimensions. If the corals are exposed for a short period to elevated temperatures, they may react by expelling pigmented symbionts, but then resume normal coloration during periods of time when no longer subjected to thermal stress. Many of the less tolerant coral species have already been killed in the peripheral zone (Table 7) and it is suspected that many of the more tolerant species will also be killed as they are subjected to the sublethal thermal stress conditions over a longer period of time. Jokiel and Coles[11] reported basically the same conditions in their Kahe Pt. study.

There is little evidence of new coral recruitment by planulae settling in the peripheral zone, so with time, the central core zone will probably encroach somewhat into the peripheral zone. It is doubtful though that the overall dimensions of the affected area will increase appreciably in size at the present discharge rate and temperature of power plant effluent. As pointed out in Section V, the intake channel seems to present a northern barrier to the movement of the plume along the nearshore environment. The attenuation of plume temperature to a tolerable level places the extreme southern boundary near Transect C (Fig. 29).

CORALLINE ALGAE

In terms of reef building and maintenance, another group of important organisms affected by the effluent were the crustose coralline algae (Appendix D). In the reef margin and reef front zones _Porolithon onkodes_, an encrusting coralline, covers more reef surface area, when considering the numerous holes, cracks, and cavernous regions of these zones, than any other organisms. _Porolithon gardineri_ forms rounded clumps of closely set branches, and in the reef margin zones is often more abundant than corals. _Porolithon gardineri_ has about the same degree of tolerance to the effluent as the corals. _Porolithon onkodes_ shows slightly greater resistance than _P. gardineri_. The reef surface covered by these two encrusting and ramose corallines in the core zone has been greatly reduced. In the peripheral zone, the _Porolithon_ kill is patchy and more or less restricted to the upper parts of surge channels, submarine buttresses and knobs. _Porolithon onkodes_ seems to be surviving in the small cracks, holes, and on the basal branches of dead ramose coral colonies. In these cryptic locations the encrusting coralline has a normal pink to red coloration. Under the influence of the effluent, this red pigmentation turns pale and finally, at death, becomes a chalky white color. Blue-green algae are usually the first organisms to recolonize the freshly killed surface (Fig. 26).

Unless another carbonate secreting organism recolonizes this important niche, erosion of the reef margin and inner part of the reef front zone will probably take place. Recent investigations at Tumon Bay revealed that *Acanthaster planci* has killed nearly all the corals in these two reef zones (both zones endure less wave exposure than Tanguisson reefs). This coral kill by the starfish at Tumon Bay is not as serious as that at the Tanguisson outfall site because the dead corals in Tumon were rapidly encrusted with coralline algae, thereby maintaining the structural integrity of the reef framework. In time, the reef margin corals at Tumon Bay will become re-established, but at the outfall site at Tanguisson, there are no such corals or coralline algae recolonizing the region where the effluent has killed them.

SECTION IX

THERMAL SIMULATION EXPERIMENTS

Jokiel and Coles[11] recently reviewed the literature on the effects of short-term exposure of reef corals to lethal temperatures. The above authors were part of a team of University of Hawaii scientists working, with support from another EPA grant, to provide information on upper thermal tolerance limits and growth rate of adult Hawaiian corals and settlement of their planulae. Unpublished laboratory data (Jokiel, personal communication) as well as field data (Jokiel and Coles[11]) indicates that lethal temperatures, for the common species of Hawaiian corals, are approximately 31-32°C; and that prolonged exposure to temperatures of 30 to 31°C may lead to sublethal effects such as loss of pigment or eventual death. They suggested that absolute temperature levels rather than the degree of thermal enrichment over seasonal temperature was the most critical factor. It was evident that temperatures above summer ambient (27°C for Hawaii) were more likely to be damaging than equal temperature increases over winter ambient. In fact, corals showing sublethal damage (pigment loss) in summer, often recovered in winter months.

The Hawaii group has suggested (unpublished work) that Hawaiian corals were probably adapted to temperatures at or below 27°C, which is the highest (summer) oceanic temperature in the Hawaii study area. They postulated that physiological races of the same coral species found in Hawaii exist in the warmer waters of the Indo-Pacific and these races may well have tolerance ranges set higher than those found in Hawaii. The Hawaii group also found (unpublished data) that the coral growth optimum fell within the normal ambient range (22-27°C) for the study area, Kaneohe Bay, Oahu.

In the Fall of 1971, the EPA requested that the Guam team aid in testing the above hypothesis and catalog the upper thermal tolerance limits for additional coral species. Guam lies within the Indo-Pacific region (Wells[16]) referred to by Jokiel and his colleagues and the island has a mean annual temperature (27.6°C) slightly greater than the maximum for Kaneohe Bay (27°C). In Guam the seawater temperature regime follows the wet and dry seasons. For example, the coolest water temperatures are found from January to April, which approximates the dry season. The warmest months are June through November, the wet season. Transitional months are usually May (sometimes June) and December. The cool months have an oceanic water temperature range of approximately 25.5 to 28.3°C with a mean of 26.8°C, for a 10 year period (Fig. 18). Warm months range from 27.3 to 29.0°C with a mean near 28.5°C. According to the above hypothesis, reef corals on Guam should be adapted to higher temperatures than Hawaiian corals.

The thermal simulation apparatus used by the University of Hawaii group utilized a heat pump and a titanium tube heat exchanger. Temperature of seawater was controlled by mixing heated with ambient temperature seawater. This system worked well but was beyond the budget and support facilities of our project. With the aid of personnel from the EPA National Water Quality Laboratory in Rhode Island, we were able to design a system that utilized commercial immersion heaters and electronic controllers (Fig. 30). The first model of our system included a delta T tracking feature. This device tracked ambient temperature and maintained experimental temperatures at 2°C increments (+2, +4, +6) above ambient. The delta T system is vital in temperate environments where diurnal temperatures ranges may fluctuate considerably. However, in Guam's tropical environment, oceanic water temperature rarely fluctuates more than 0.5 to 1°C diurnally and only 3°C annually. It is also clear from work by Jokiel and Coles[11] and others that temperature maxima to which corals are most logically adapted are near summer ambient. Therefore it would be of little value to test corals at temperatures based on ambient values below summer ambient. We therefore, modified our control system to hold the desired 2°C increments above a summer mean ambient of 28.5°C. This resulted in experimental temperatures of 30.5°C (+2), 32.5°C (+4), and 34.5°C (+6).

Our experimental temperatures fluctuated somewhat due to controller variability and numerous power failures that were common in Guam during the research period. We exerted every effort to hold our experimental temperatures within ± 0.5°C of the desired values. No attempt was made to hold the ambient (control) tanks to 28.5°C. They were allowed to fluctuate normally.

Corals were acclimated for one to two weeks prior to introduction to the simulator (Fig. 31). The corals were placed in pans of fresh seawater and floated in the experimental tanks until they reached the experimental temperature (two to three hours). They were then arranged in rows within the tanks. The tanks were set up in replicates of three for each experimental temperature (Fig. 30). The rows of coral specimens were alternated between tanks to avoid bias in placement. Coralla were placed on inverted specimen jars to prevent bacterial contamination that often

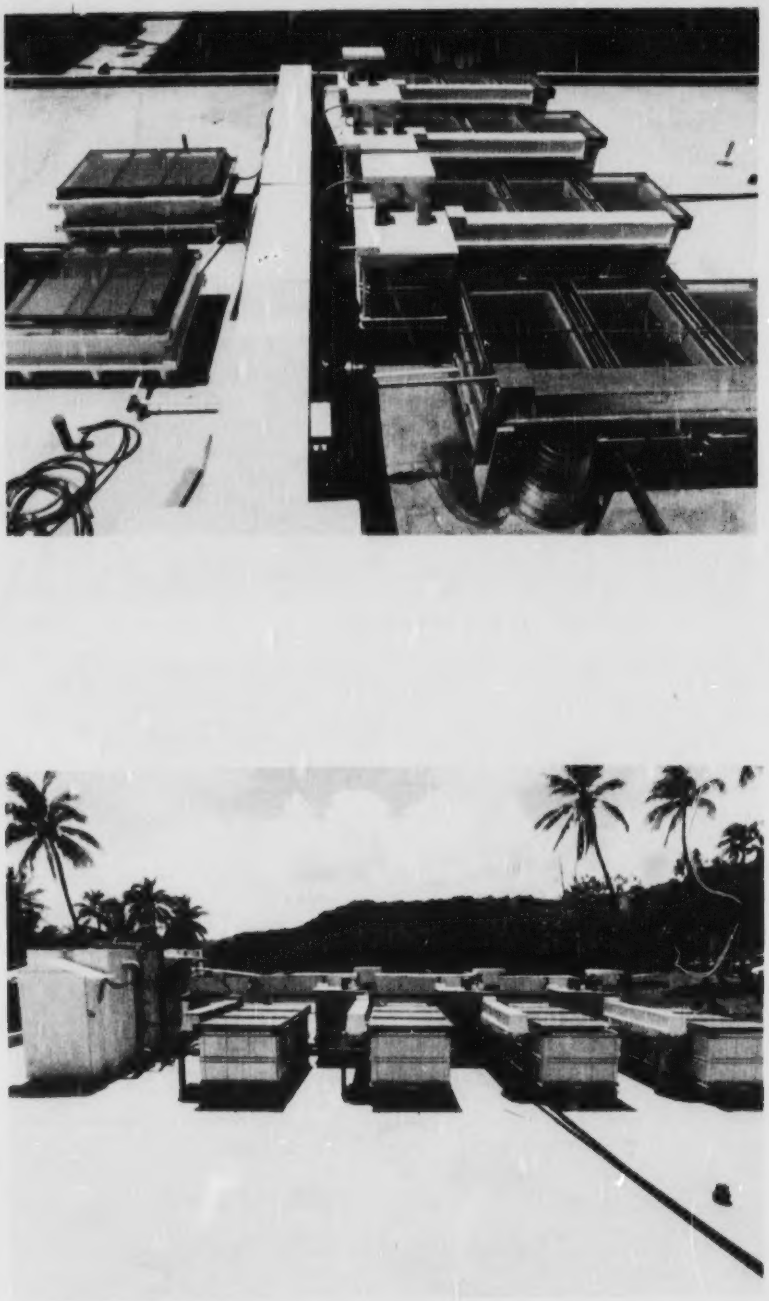

Figure 30 Thermal simulation device

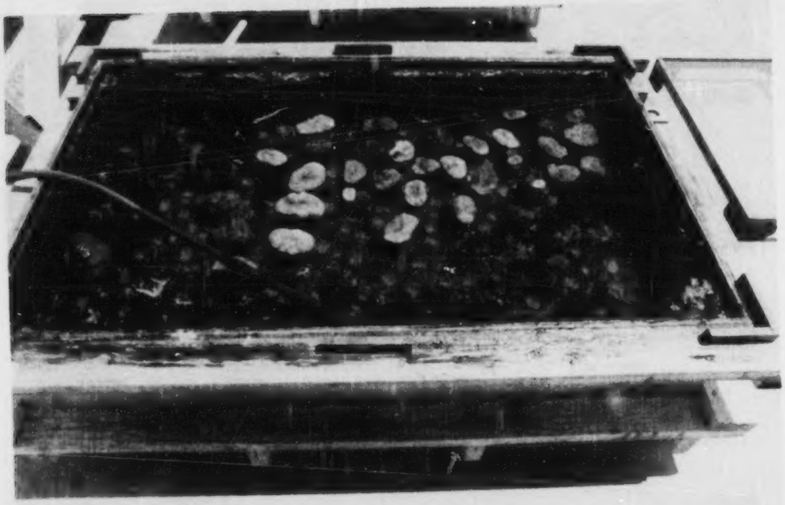

Figure 31 Acclimation tank

occurs when the coralla are in contact with the bottom. It was also necessary to place one layer of plastic screen over each tank to cut down (by about 30%) on the intense sunlight of our Latitude (13°N). Unless this was done, the corals tended to lose their pigments and often died in the shallow tanks even in the absence of thermal stress. The 12 experimental tanks were 79 to 59 by 50 cm and rigged with stand-pipes to hold the water level at 39 cm (182 liters). Uncontaminated seawater flowed constantly through the system at four liters/minute. A scanning telethermometer with recorder was set to minotor all tanks as well as the ambient control tanks, continuously.

The first experiments were conducted over 30 day periods to ensure adequate time for measurable growth, at least in the control corals. This period was later reduced to 14 days to allow a greater number of species to be tested for thermal tolerance. In most cases, percent gain of the coral skeleton was still detectable.

Eighteen species of hermatypic corals belonging to 12 different genera were tested (Table 9 and Figs. 32 to 49). Some of the species were tested more than once and the total number of experimental runs was 24. In all, 1,218 individual coral specimens were tested over a total of 544 test days.

Mean ambient (control) temperatures fluctuated between 27.5 and 29.5°C (2°C span). They rarely were more than ± 1°C from summer ambient (28.5°C) and usually were within ± 0.5°C. Three hundred two control specimens were tested over the 18 species. Only three specimens died (1%). The dead corals were restricted to three of the species (Figs. 32, 43, and 48). These losses were considered as chance occurences, which reduces the percent dead to zero.

In the 30.5 (+2) tanks the temperatures fluctuated between 29.5 and 31.5 (2°C) span). One of the 24 test runs was eliminated because of a temperature control failure. Of the other 23, seven fell to a mean of 29.5°C, one rose to a mean of 31.5°C and the remainder were at or within ± 0.5°C of 30.5°C.

Two hundred ninety-six specimens were tested over the 18 species. Of these, 28 died (9%). The dead corals were restricted to eleven species. (Figs. 32, 33A, 35, 37, 38, 40B, 41, 43, 45, 46 and 49). Nine species lost one to three individuals each, one species lost seven and one lost nine. Among the losses, 12 were considered likely due to chance. This would reduce the number of corals killed by heat to 16 (5%). The apparently legitimate losses were seven by _Fungia scutaria_, and nine by _Leptoria phrygia_. The loss of _F. scutaria_ is thought to be reasonable because this is a deep water species in Guam and not normally subjected to fluctuating temperatures. We suspect that the loss of nine out of nine _L. phrygia_ is possibly due to some form of contamination in that experimental run but cannot say this with assurance. All the specimens were "healthy" until the 10th day of the 14 day experiment. Although the few losses at +2 above summer ambient might well be indicative of the beginning of heat damage, we prefer to be conservative and assume most of the deaths were chance occurrences.

The 32.5°C (+4) experimental temperature fluctuated between means of 31.5 and 33.5°C (2°C span). Of the 24 experiments, only one mean temperature rose to 33.5 and three fell to 31.5°C. The remainder were at or within ± 0.5°C of the desired temperature (32.5°C).

Three hundred five specimens were tested over the 18 species. Of these, 210 specimens died (69%). Significant numbers of specimens died among 15 of the 18 species. Six of the deaths are considered as possibly due to chance (three out of nine for *Pavona obtusata* and three out of 35 for *Acropora aspera*, Figs. 36 and 43). No deaths were recorded in the single experiment with *Platygyra rustica* (Fig. 49). Moreover, in one of two experiments with *Psammocora contigua* (Fig. 33B), one of three experiments with *Porites lutea* (Fig. 40C) and one of two experiments with *Galaxea hexagonalis* (Fig. 42A), no specimens were killed. The surviving *P. contigua* and *P. lutea* were at temperatures of 32.0°C which is within the ± 0.5°C tolerance. Both failed to survive when temperatures were raised in duplicate experiments from 32 to 33 and 32.5°C respectively. *G. hexagonalis* and *P. rustica* were at 31.5°C, a full degree below the desired experimental temperature of 32.5°C and their survival might well have been favored. *G. hexagonalis* failed to survive when temperatures were raised in duplicate experiments from 31.5 to 32°C (Fig. 42B). It is therefore evident from duplicate experiments run with *P. contigua*, *P. lutea* and *G. hexagonalis*, that if the experimental temperatures had been held at the desired mean of 32.5°C there might well have been no survivors. It is apparent that all three species were favored, where they survived, by lower than desired temperatures. No duplicate experiments were conducted with *P. rustica* but it is quite likely that it may also have failed to survive if held at the correct experimental temperature.

The data suggest that, of the 18 coral species tested, the majority, if not all, should not survive mean temperatures between 32 and 33°C over periods of usually less than 14 days (Table 9 and Figs. 32 to 49). *Stylophora mordax* (Fig. 48) and *Acropora palifera* (Fig. 45) failed to survive even at 31.5°C, and *Leptoria phrygia* (Fig. 46) all died at 30.5°C (possibly contamination).

The 34.5°C (+6) temperatures fluctuated between 33 and 35°C (2°C). Of the 24 experiments only one rose to 35.5 and two fell to 33.0 and 33.5 respectively. The remainder were held within ± 0.5°C of the desired 34.5°C.

Three hundred fifteen specimens were tested and three hundred fifteen died (100%). None of the 18 species survived the +6 regime (Figs. 32 to 49).

Our bioassay attempted to locate thermal death point for each coral by bracketing with +2°C increments held at ± 0.5°C of the desired experimental temperatures. This is a rather broad bracket and makes precise location of thermal death point difficult. We know the lowest test temperature at which all specimens survived and the highest test temperature at which all were dead. Therefore, we can only provide a range of minimum and maximum test temperatures between which the thermal death points can be expected to lie.

Of the 18 species of Guam corals tested, Table 9 shows that all were killed at some point between 29.0 and 34.5°C (delta T's +0.5 to +6.0°C above summer ambient, 28.5°C). This is a rather wide span of 5.5°C. Even if the L. phrygia experiment is omitted because of potential contamination of the +2 group, the 29.5°C level found in five species (Table 9) is considered low and resulted from failure to control, in several cases, the desired lower experimental temperature (30.5°C, +2°C). This is unfortunate because of the gap it leaves between the normally sublethal +2 and the lethal +4 regimes. It is doubtful that few, if any, of the corals tested would die at 29.5°C, only 1°C over summer ambient. The remaining 12 species had examples of survivors at test temperatures of 30-32°C (Table 9, Figs. 32 to 49).

While our data are by no means conclusive, we would expect that the majority of the species tested have a mean death point between 30 and 33°C (3°C span). We suspect that the lower range is nearer 31.0. Sublethal effects might well be expected to occur at or below 30°C.

Next we must view these data in a perspective that includes the power plant. While we do not doubt that coral species may endure temperatures, for short periods of time above the range shown herein, the power plant represents continual discharge of effluent and constant exposure of corals to thermal stress. Figure 19 shows the mean outfall temperature for a 28 month generating period to be 34.7°C. The highest test temperature where death occurred was 34.5°C. In other words, all corals tested died at temperatures 0.2°C or more below the 28 month mean (Table 9). During the last 12 months of plant operation observed, both Units 1 and 2 were on the line and the mean outfall temperature was 36°C (+7.5°C over summer ambient), 1.5°C or more over the highest test temperature. It is therefore evident that coral species that die in a range between 30 and 33°C are not likely to survive exposure to prevailing plant temperatures.

The data in Section VI show that lethal temperatures can occur along the

Table 9. ORDER OF RESISTANCE AND TOLERANCE LIMITS OF CORAL SPECIES TESTED IN THERMAL SIMULATOR.

SPECIES	No. Experimental days.	No. of Corals per test tank (12 tanks)	Highest temp.at which corals were alive	Lowest temp.at which corals were dead	Range of difference
Pavona obtusata	30	9	32.0	34.5	2.5
Psammocora contigua	14-30	30	32.0	33.0	1.0
Acropora aspera	14	35	32.0	33.0	1.0
Porites lutea	30	33	32.0	32.5	0.5
Platygyra rustica	14	12	31.5	34.0	2.5
Pavona frondifera	30	6	31.5	33.5	2.0
Galaxea hexagonalis	14-30	21	31.5	32.0	0.5
Fungia scutaria	30	12	31.0	33.0	2.0
Pocillopora damicornis	30	48	31.0	32.0	1.0
Pavona varians	30	9	30.5	32.5	2.0
Favia stelligera	30	9	30.5	32.5	2.0
Pocillopora setchelli	14	12	30.0	32.0	2.0
Pavona decussata	14-30	18	29.5	32.0	2.5
Acropora nasuta	14	12	29.5	32.0	2.5
Millepora platygyra	14	12	29.5	32.0	2.5
Acropora palifera	14	3	29.5	31.5	2.0
Stylophora mordax	14	12	29.5	31.5	2.0
Leptoria phrygia	14	9-12	29.0	30.5	1.5
			29.0-32.0 diff.=2.5 $\bar{X}$=30.7(31.0) Sd=±1.1 °C	30.5-34.5 diff.=3.0 $\bar{X}$=32.4 Sd=±1.0°C	

Mean range 31.0-32.5 (31-33)
diff.=1.5 °C

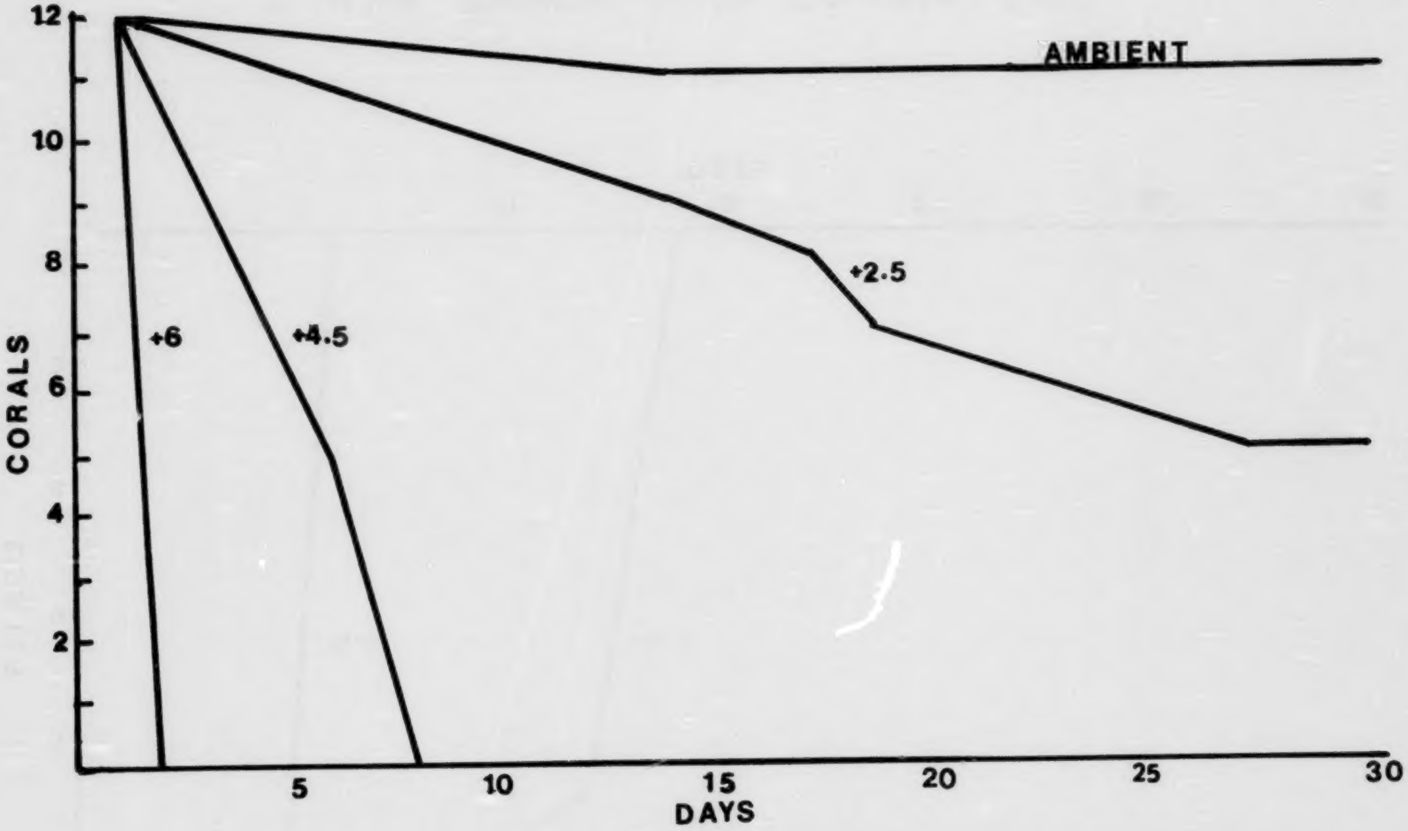

Figure 32 *Fungia scutaria*

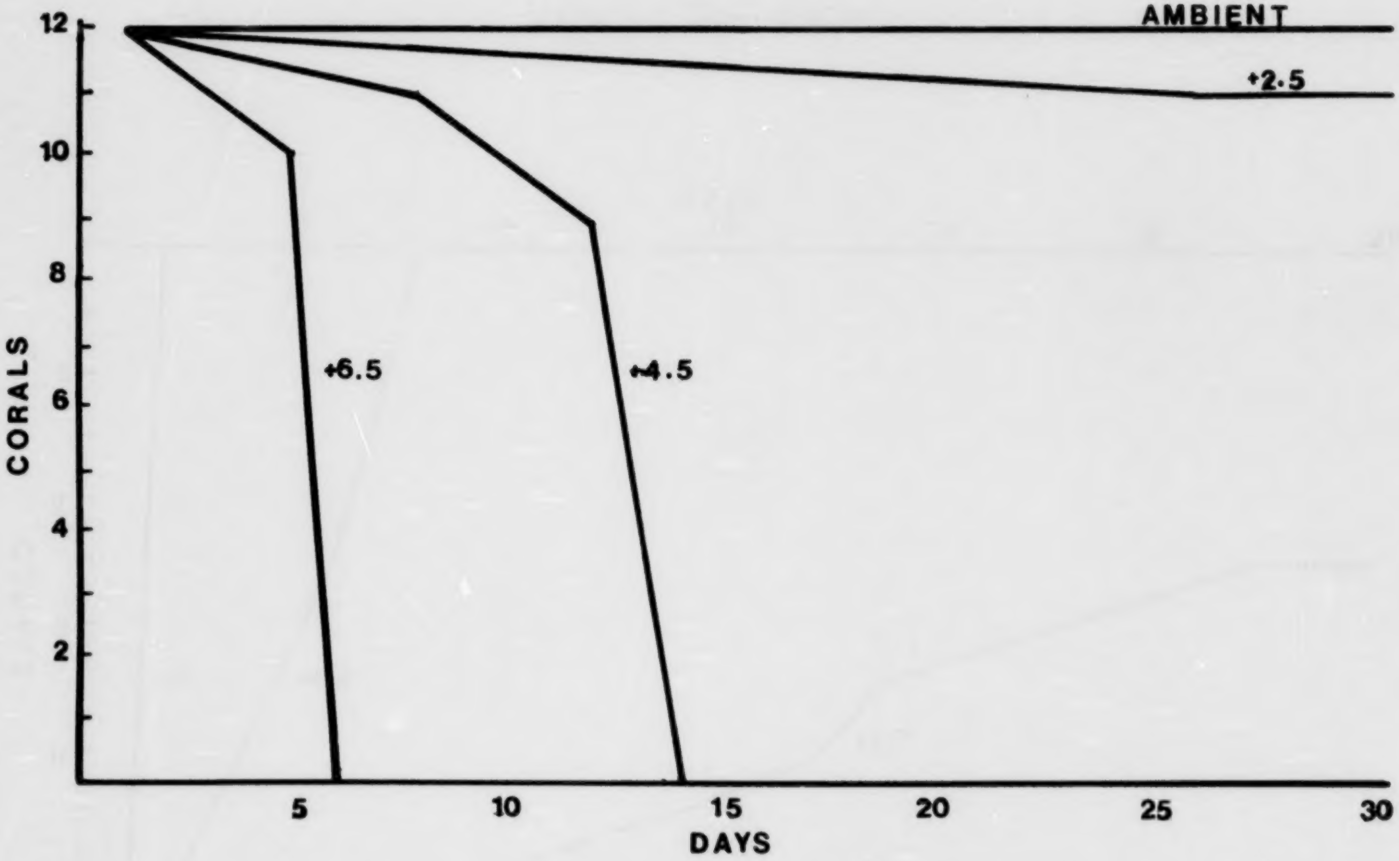

Figure 33 A. *Psammocora contigua*. (Mean ambient = 29. 0°C).

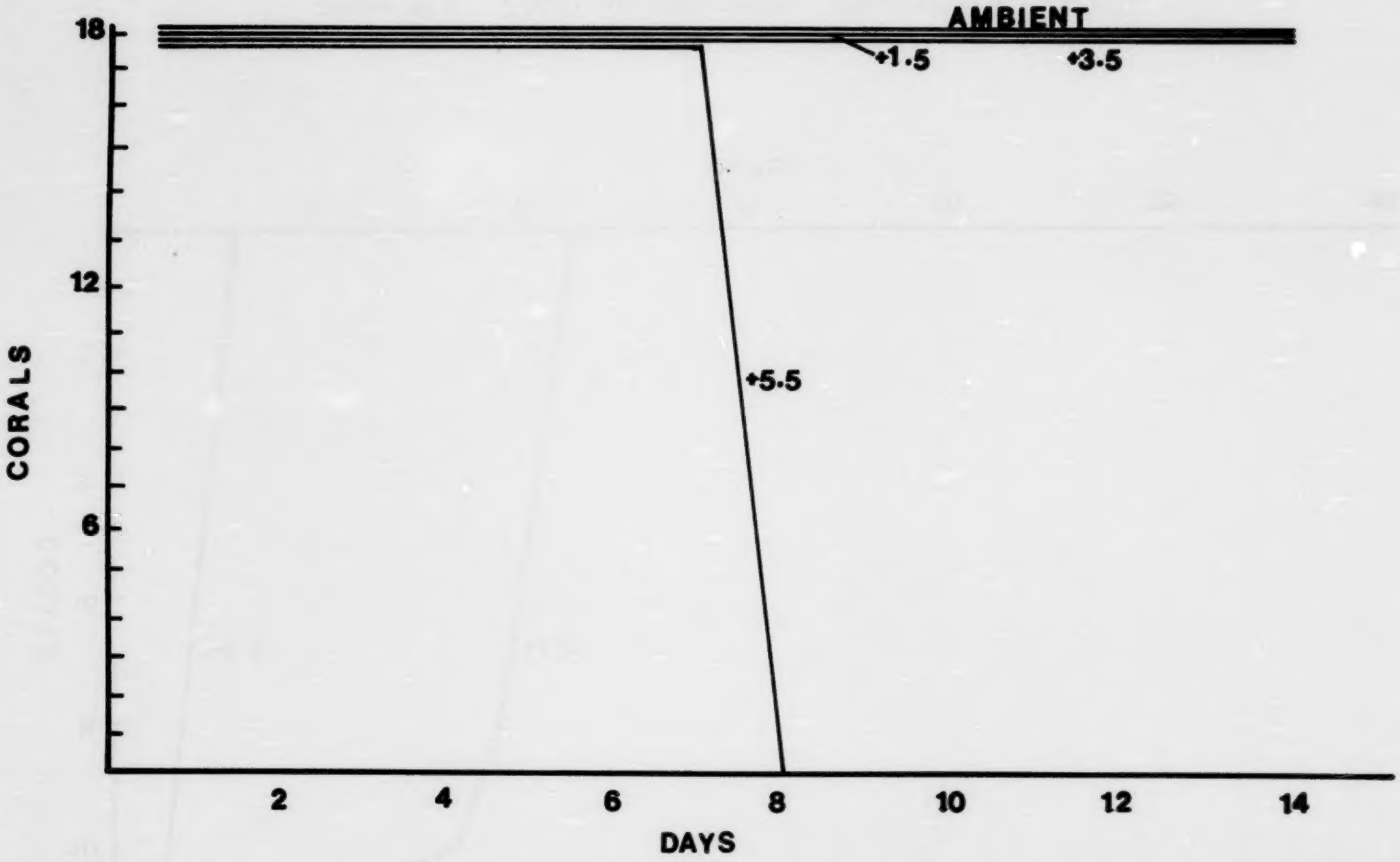

Figure 33 B. Psammocora contigua. (Mean ambient = 28.0°C).

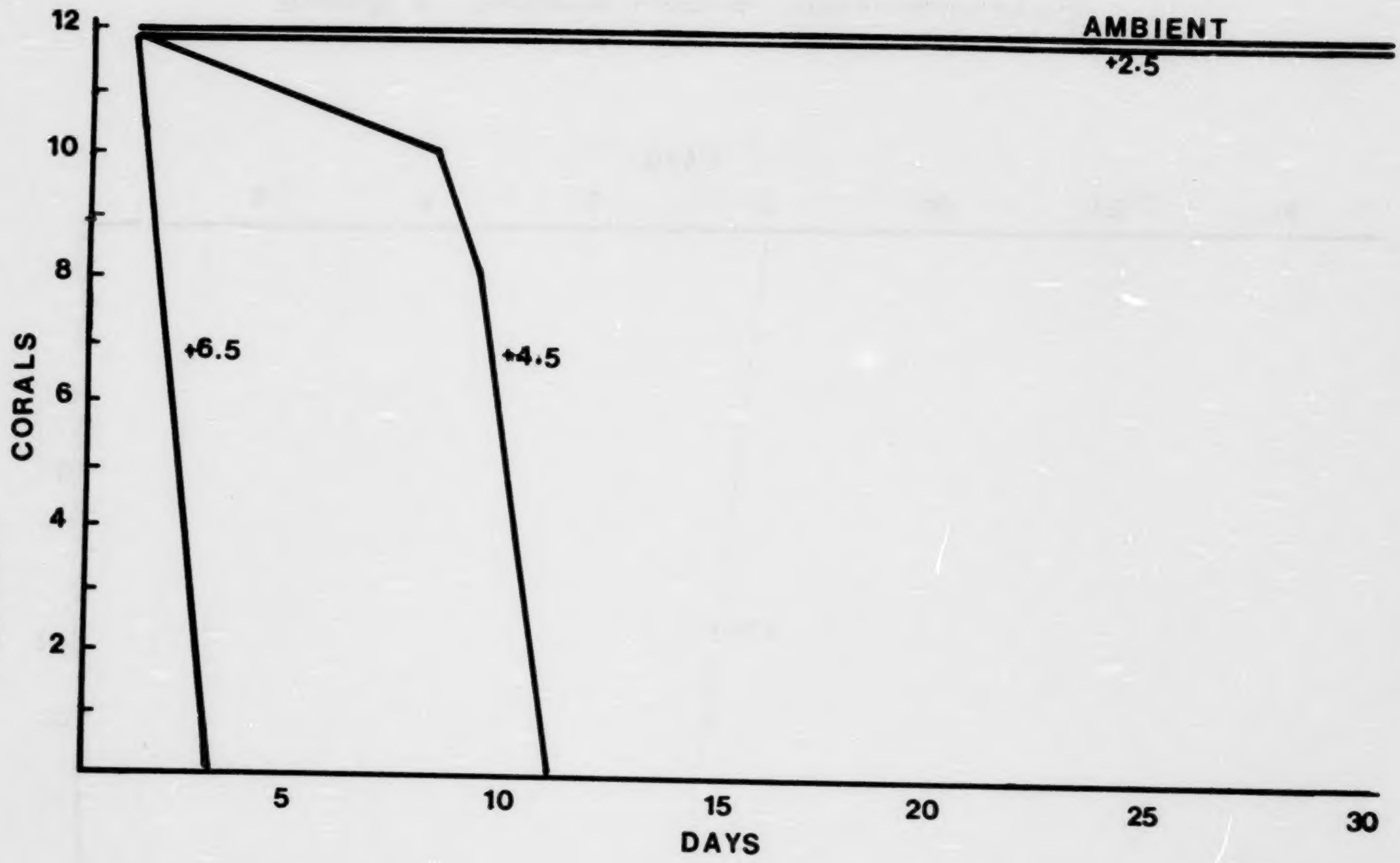

Figure 34 A. *Pocillopora damicornis*. (Mean ambient = 29.0°C).

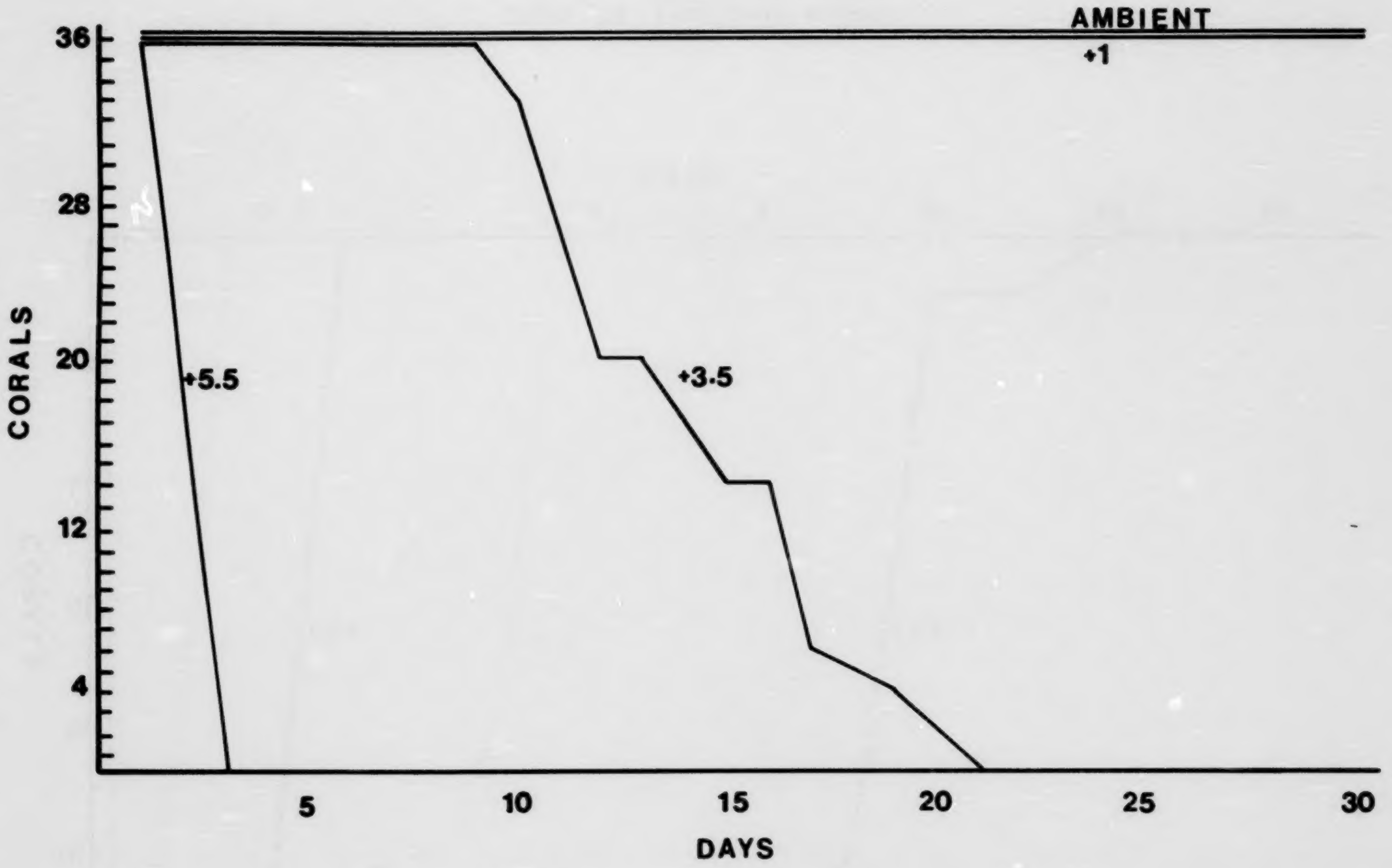

Figure 34 B. *Pocillopora damicornis*. (Mean ambient = 27.5°C).

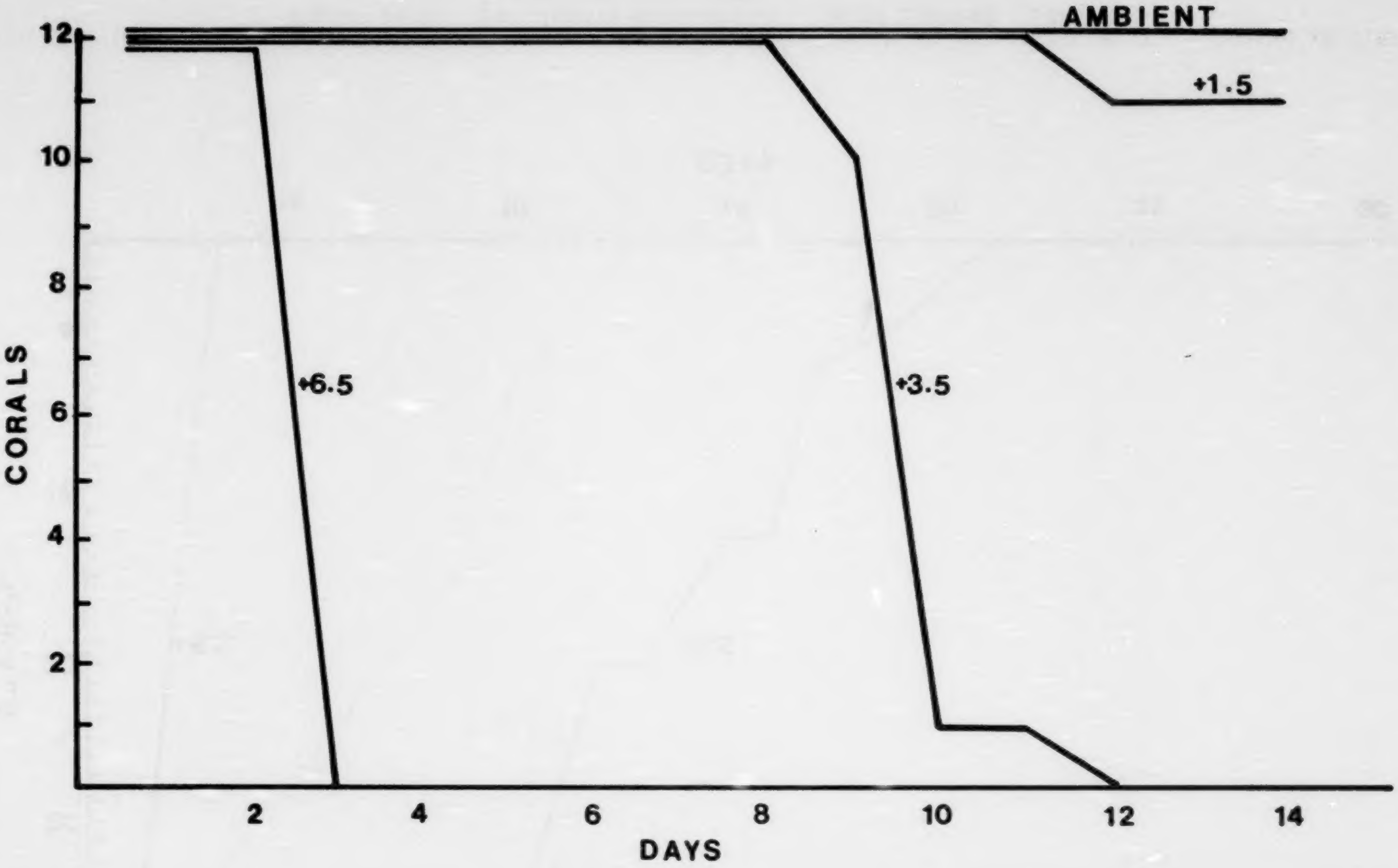

Figure 35 *Pocillipora setchelli*

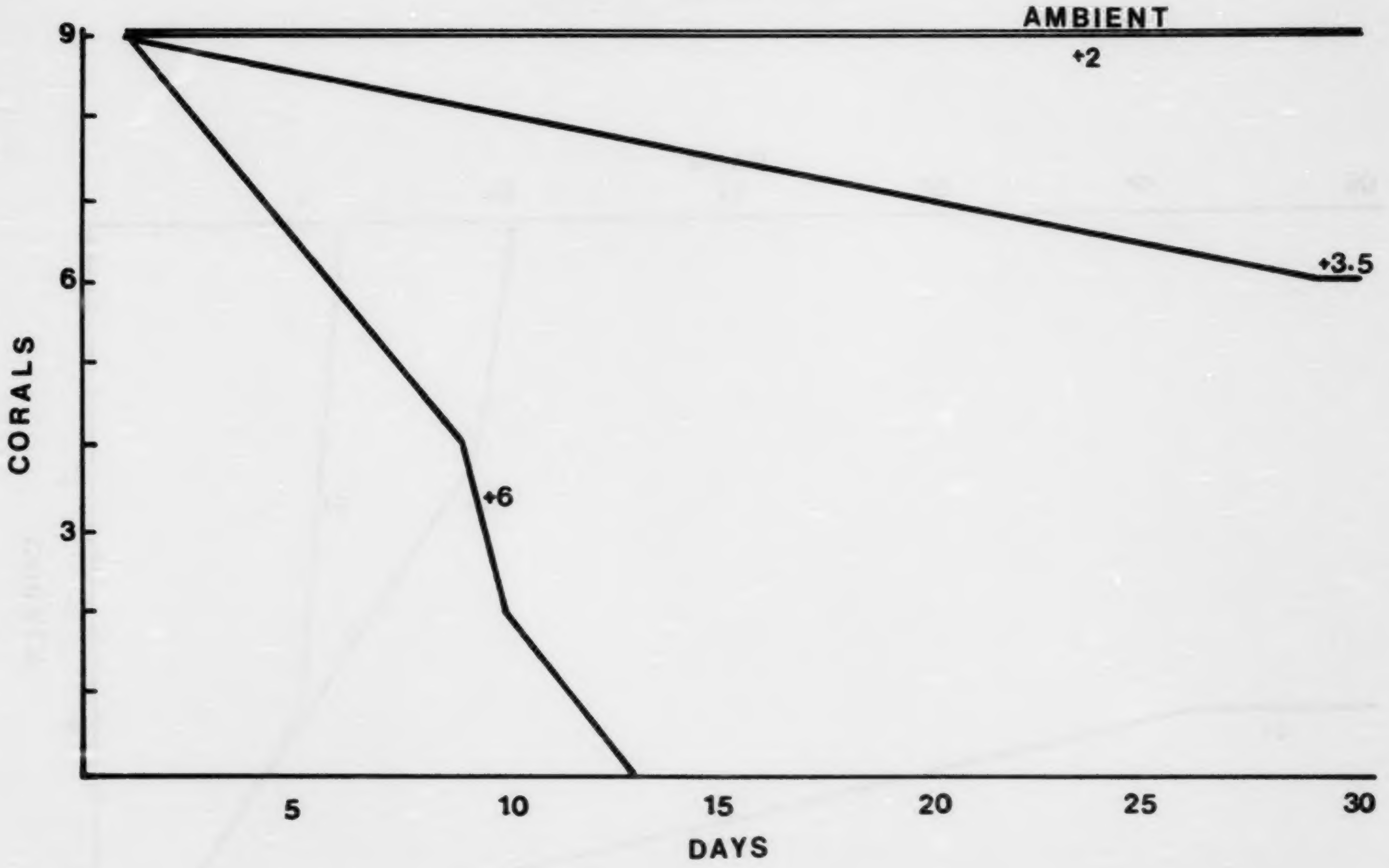

Figure 36 Pavona obtusata

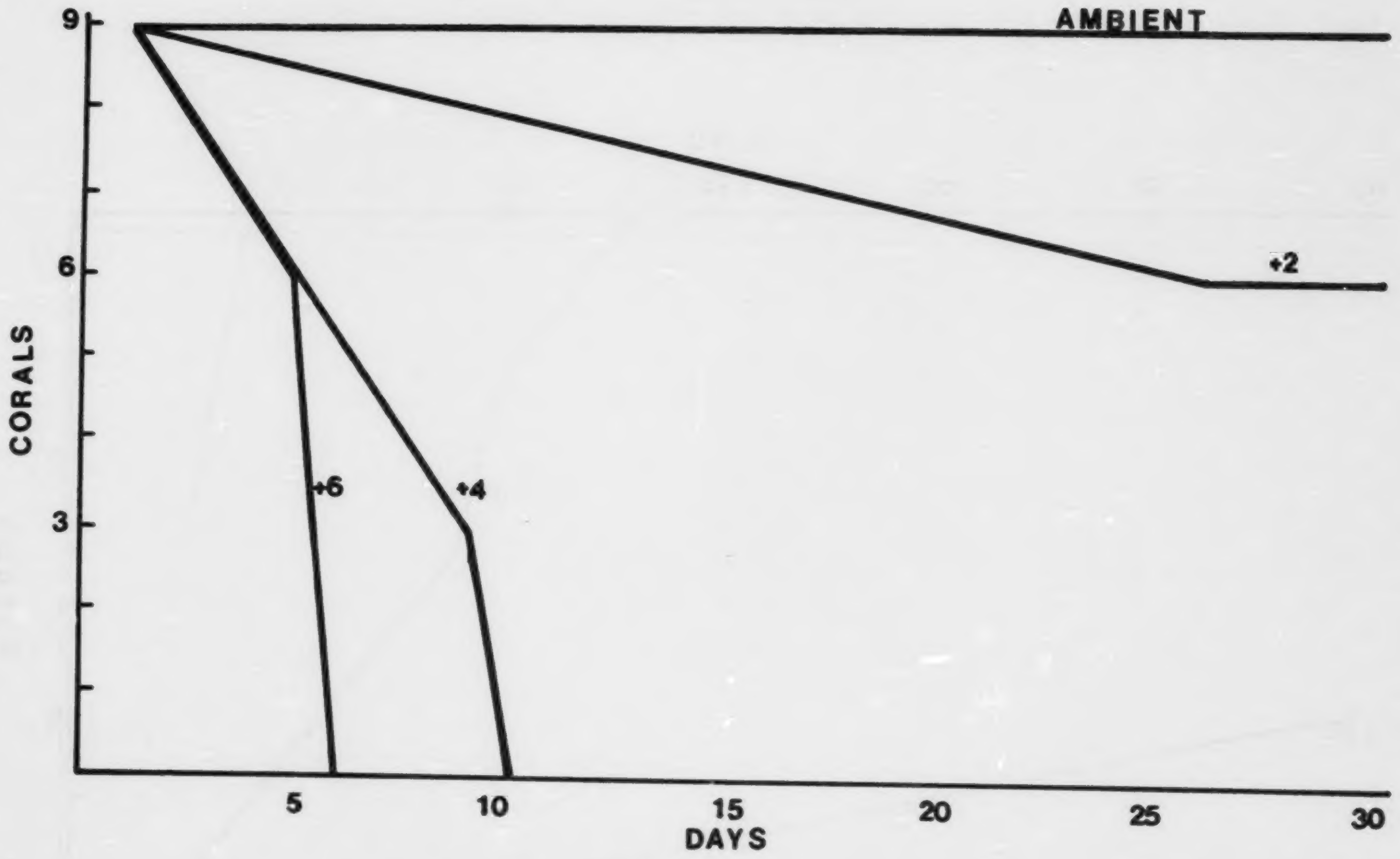

Figure 37 *Pavona varians*

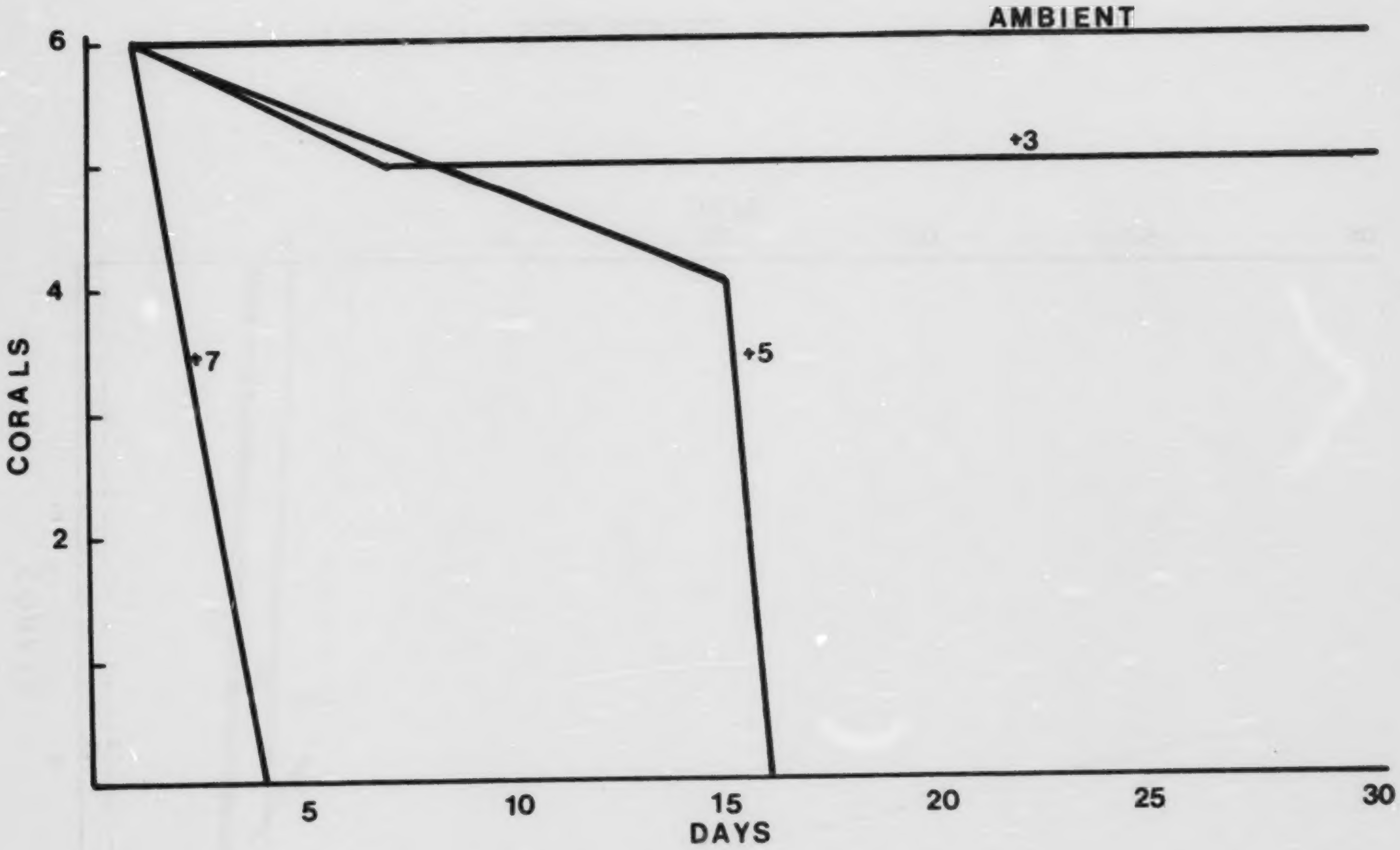

Figure 38 Pavona frondifera

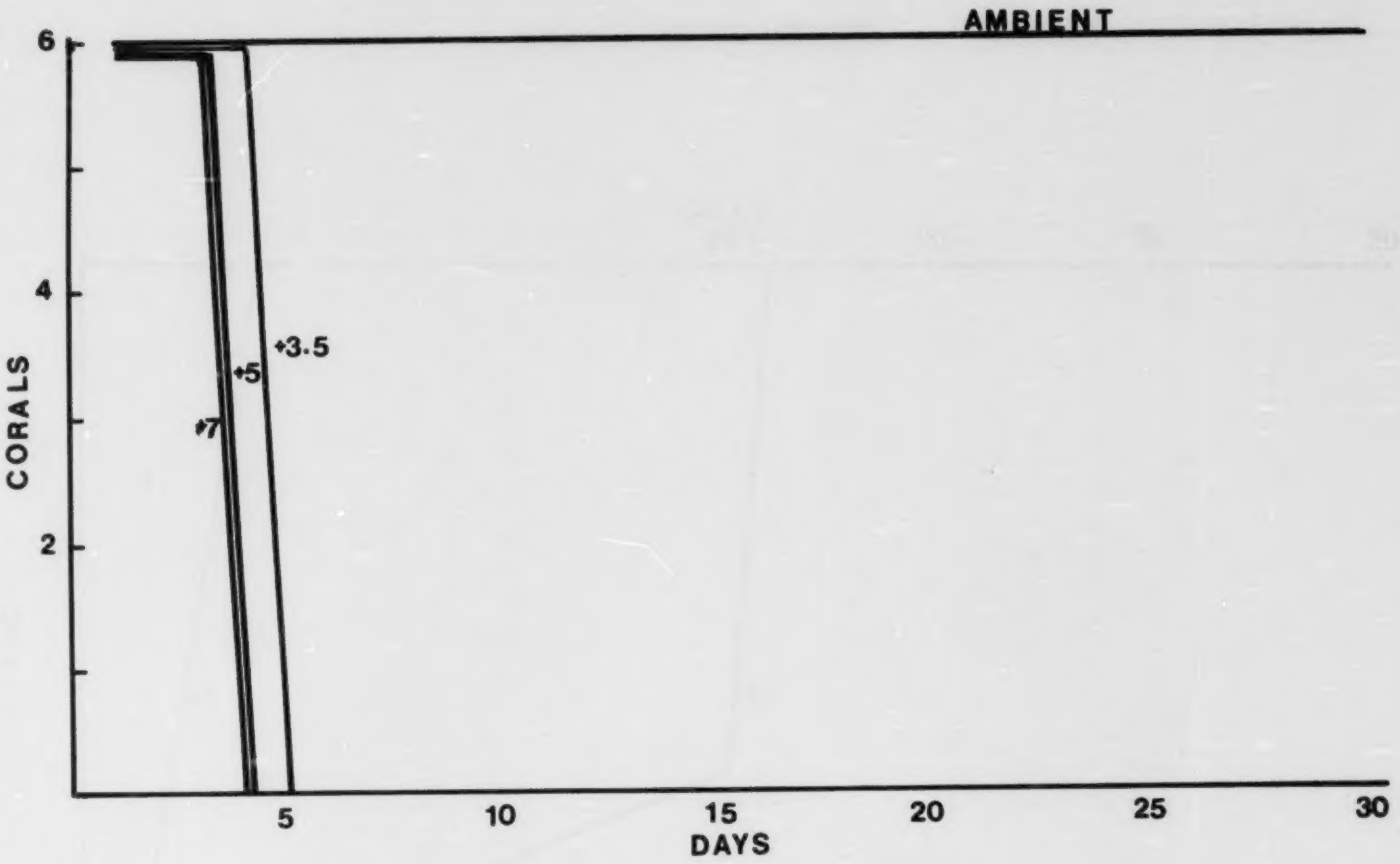

Figure 39 A. Pavona decussata. (Mean ambient = 29.5°C).

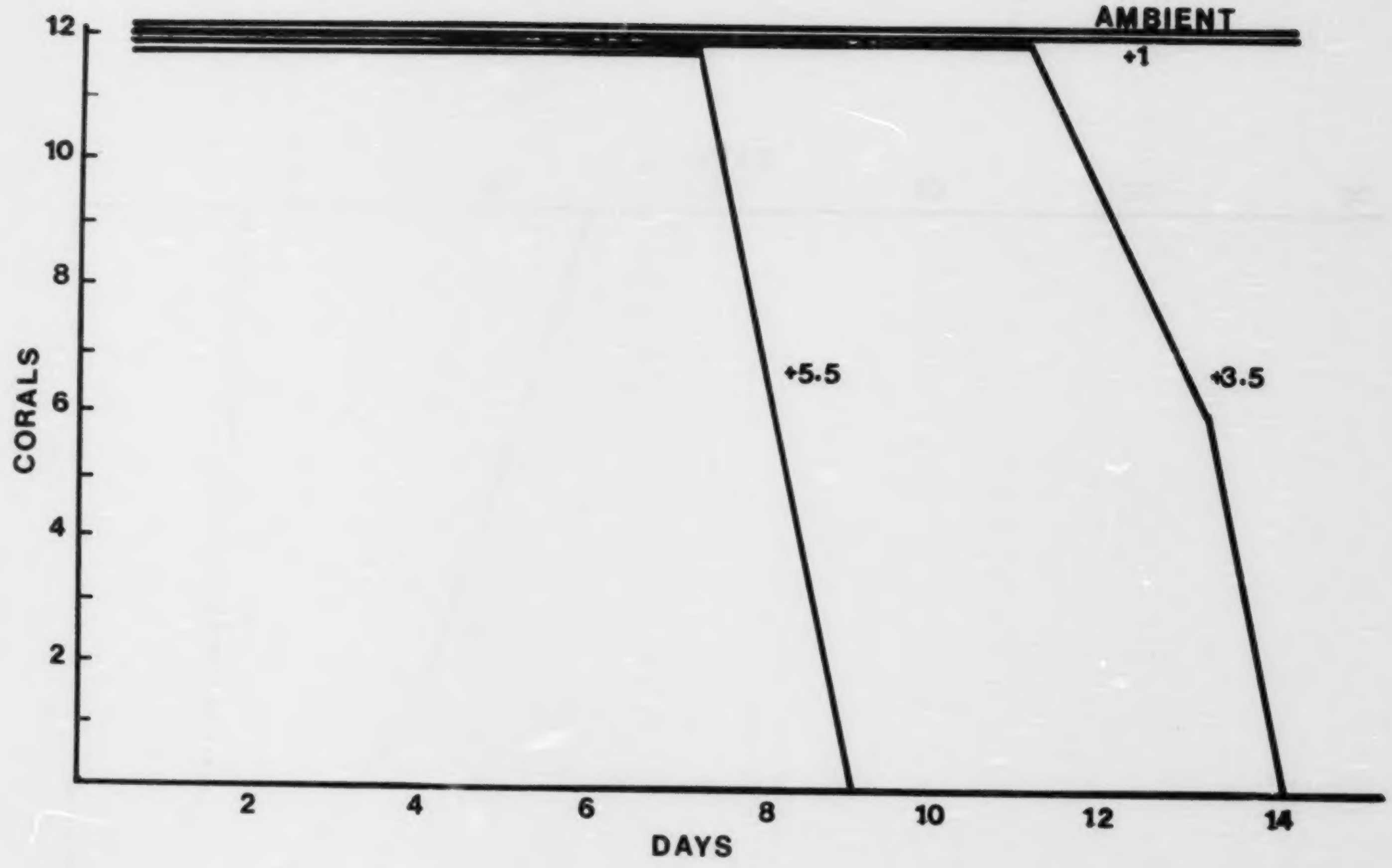

Figure 39 B. *Pavona decussata*. (Mean ambient = 28.5°C).

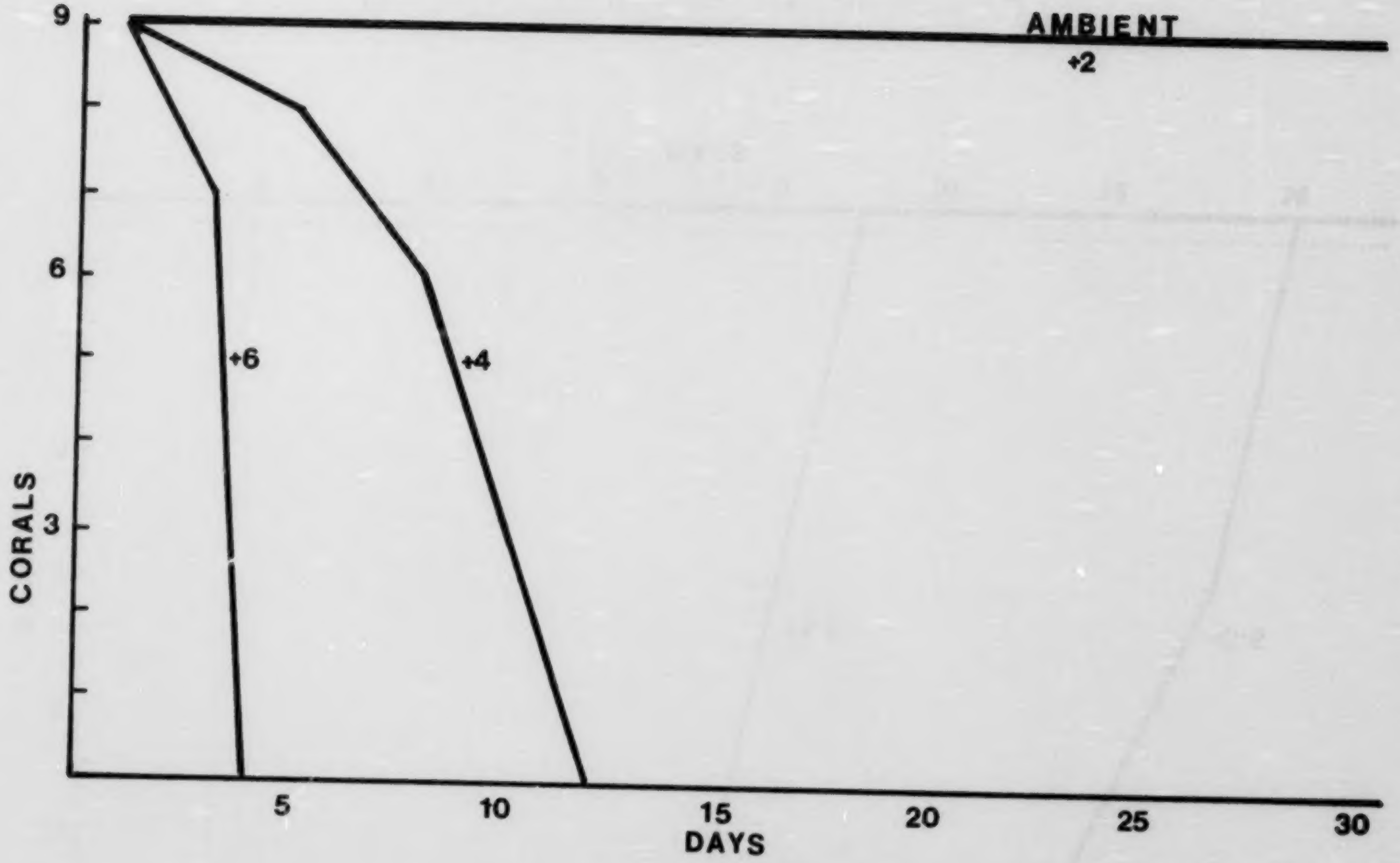

Figure 40 A. Porites lutea. (Mean ambient = 28.0°C).

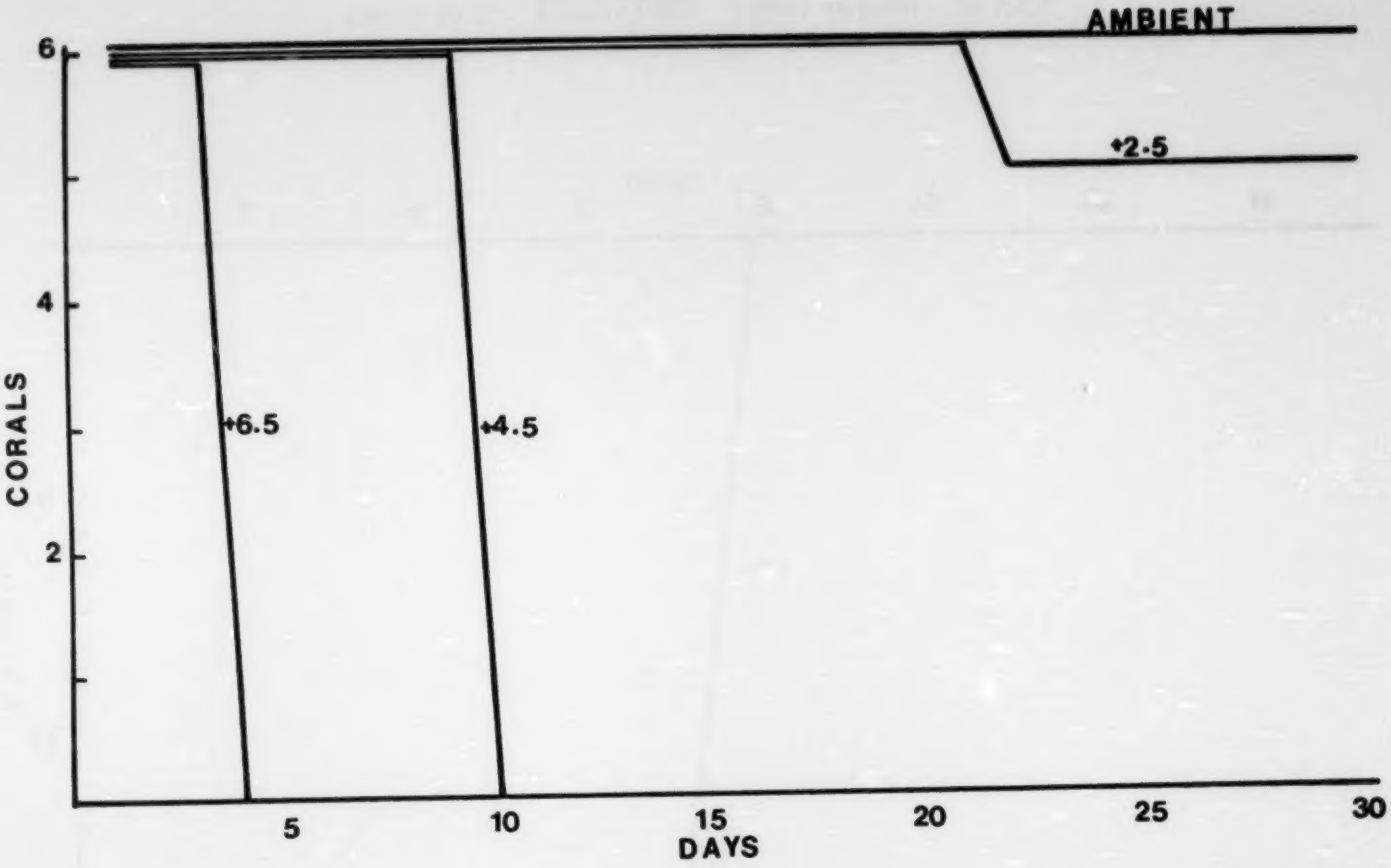

Figure 40 B. *Porites lutea*. (Mean ambient = 29.0°C).

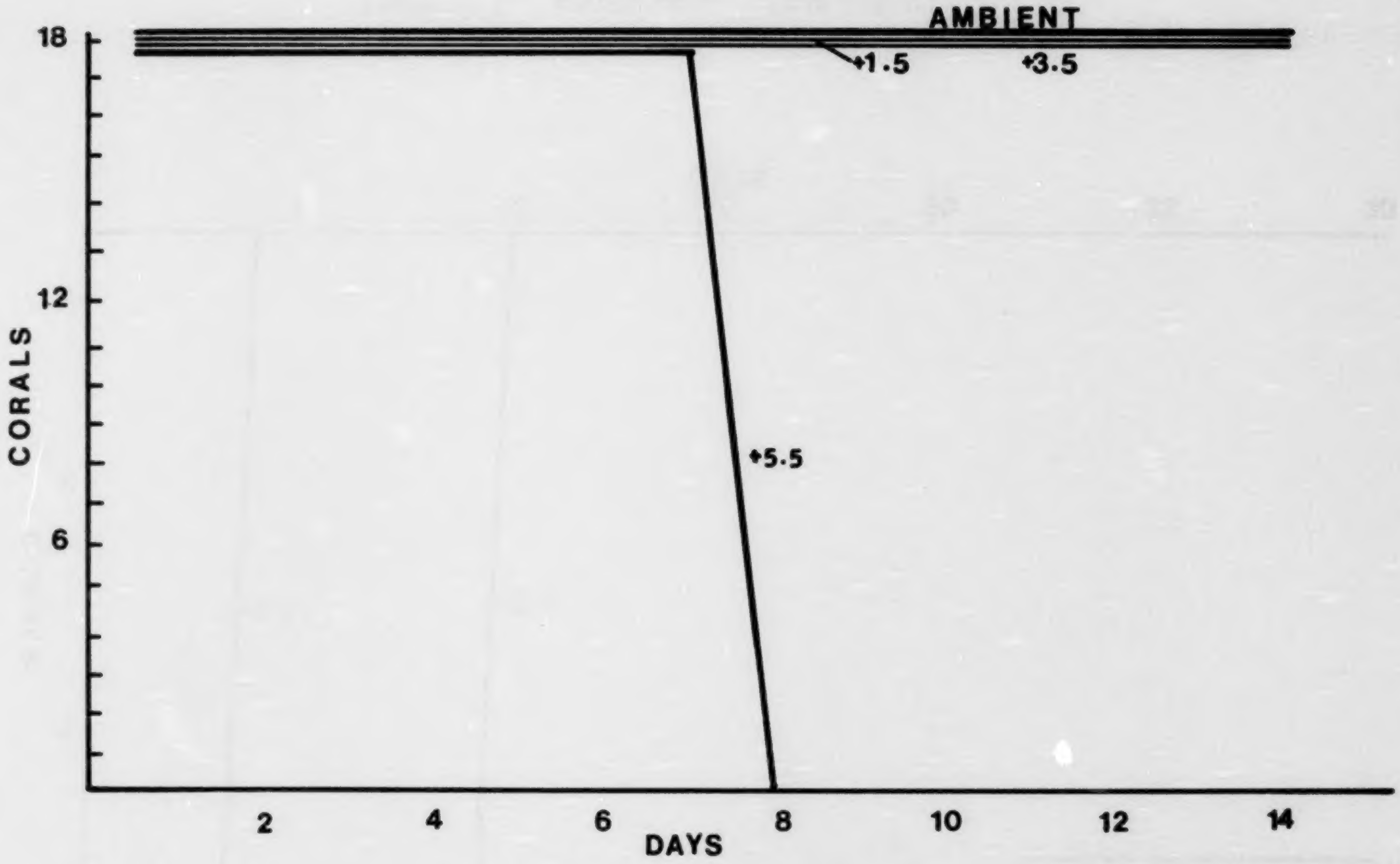

Figure 40 C. *Porites lutea.* (Mean ambient = 28.0°C).

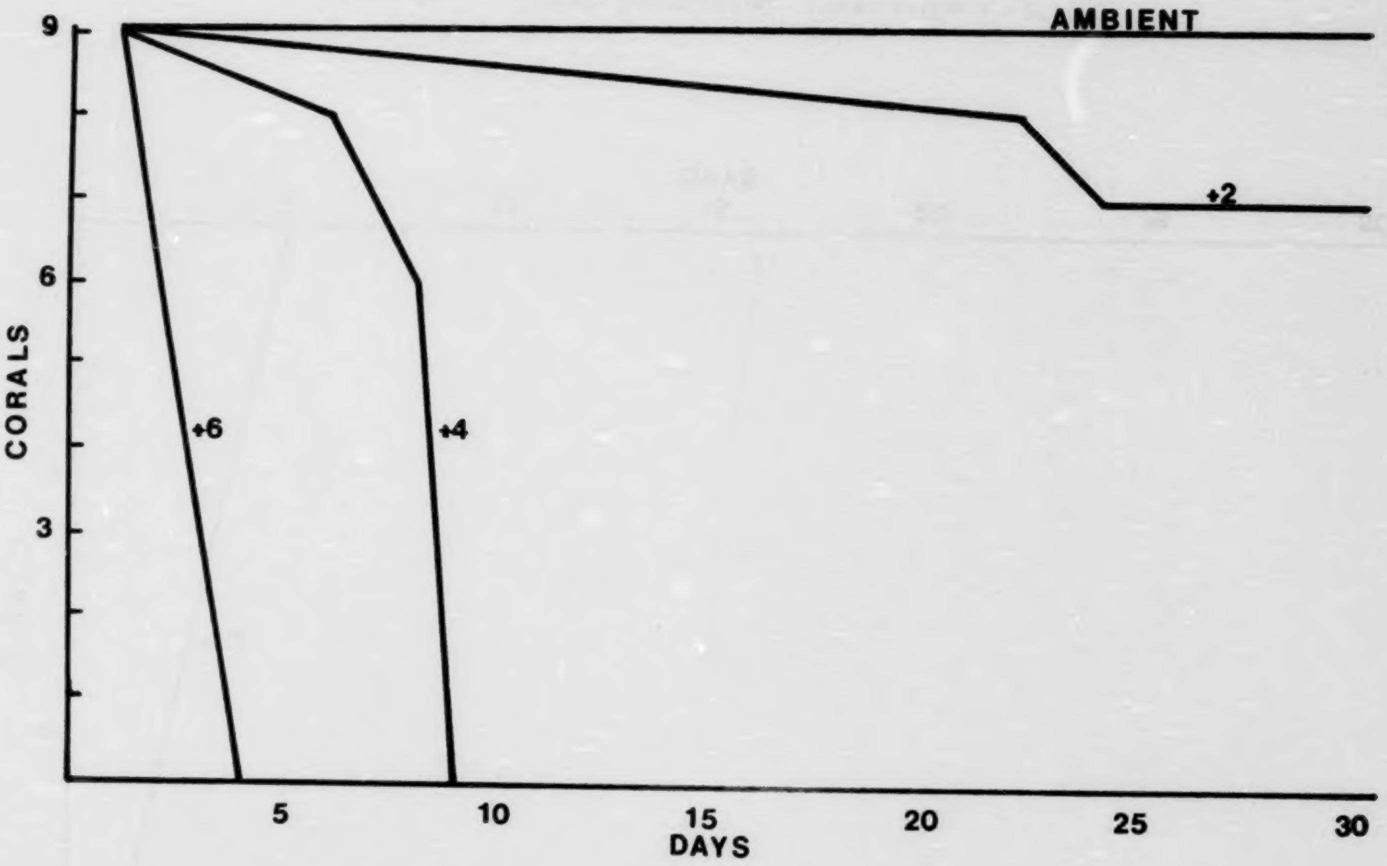

Figure 41 Favia stelligera

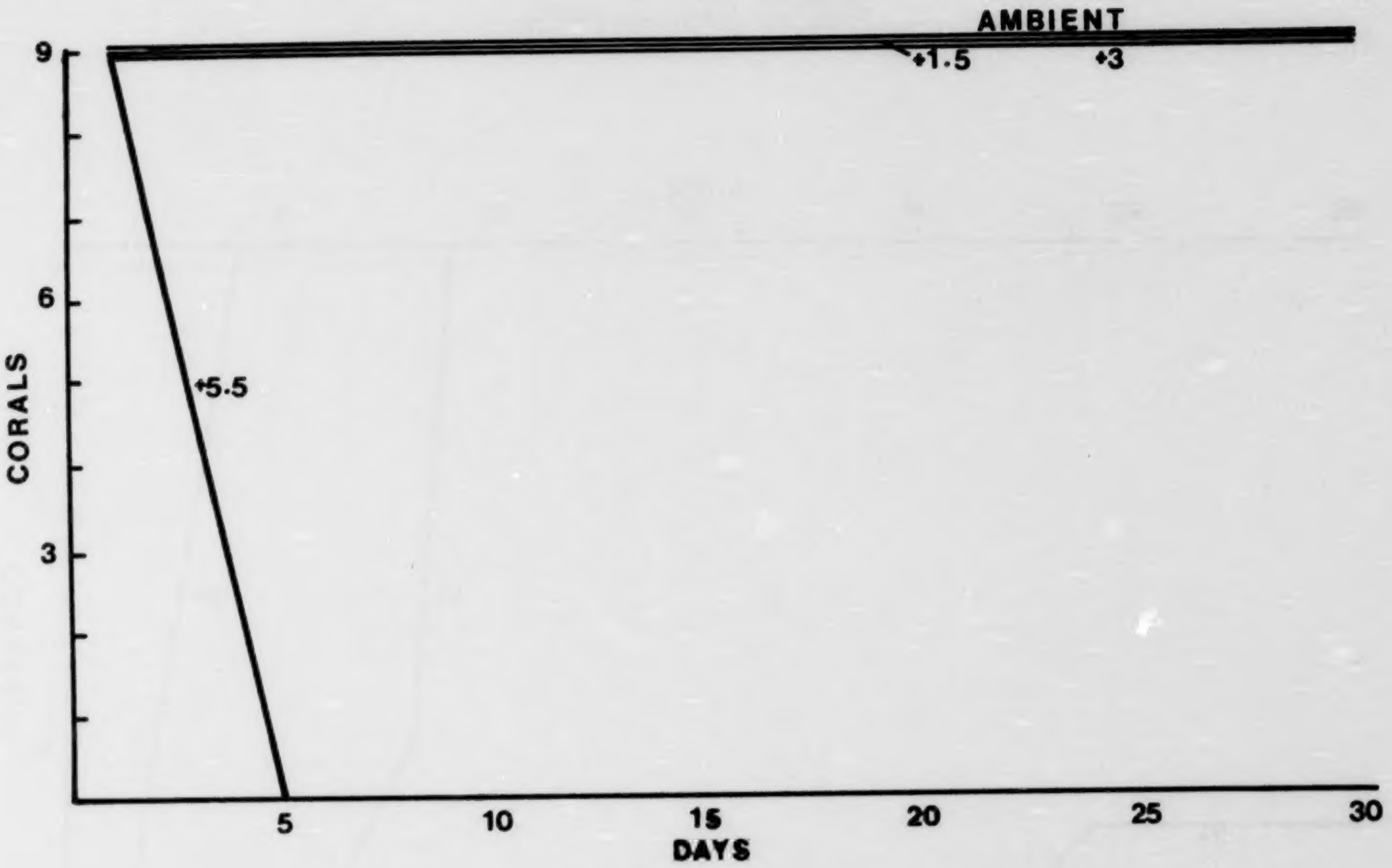

Figure 42 A. Galaxea hexagonalis. (Mean ambient = 27.5°C).

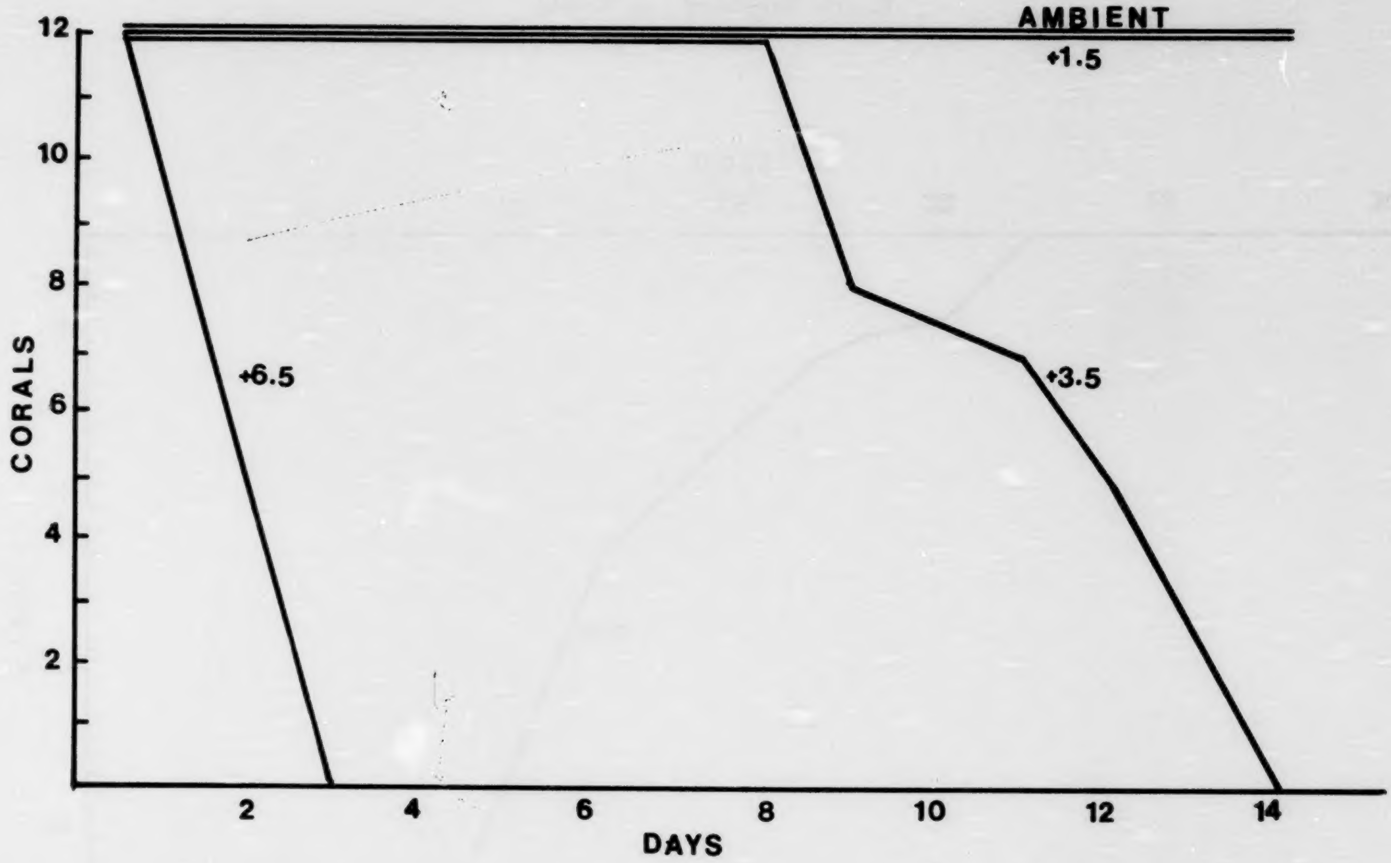

Figure 42 B. Galaxea hexagonalis. (Mean ambient = 29.5°C).

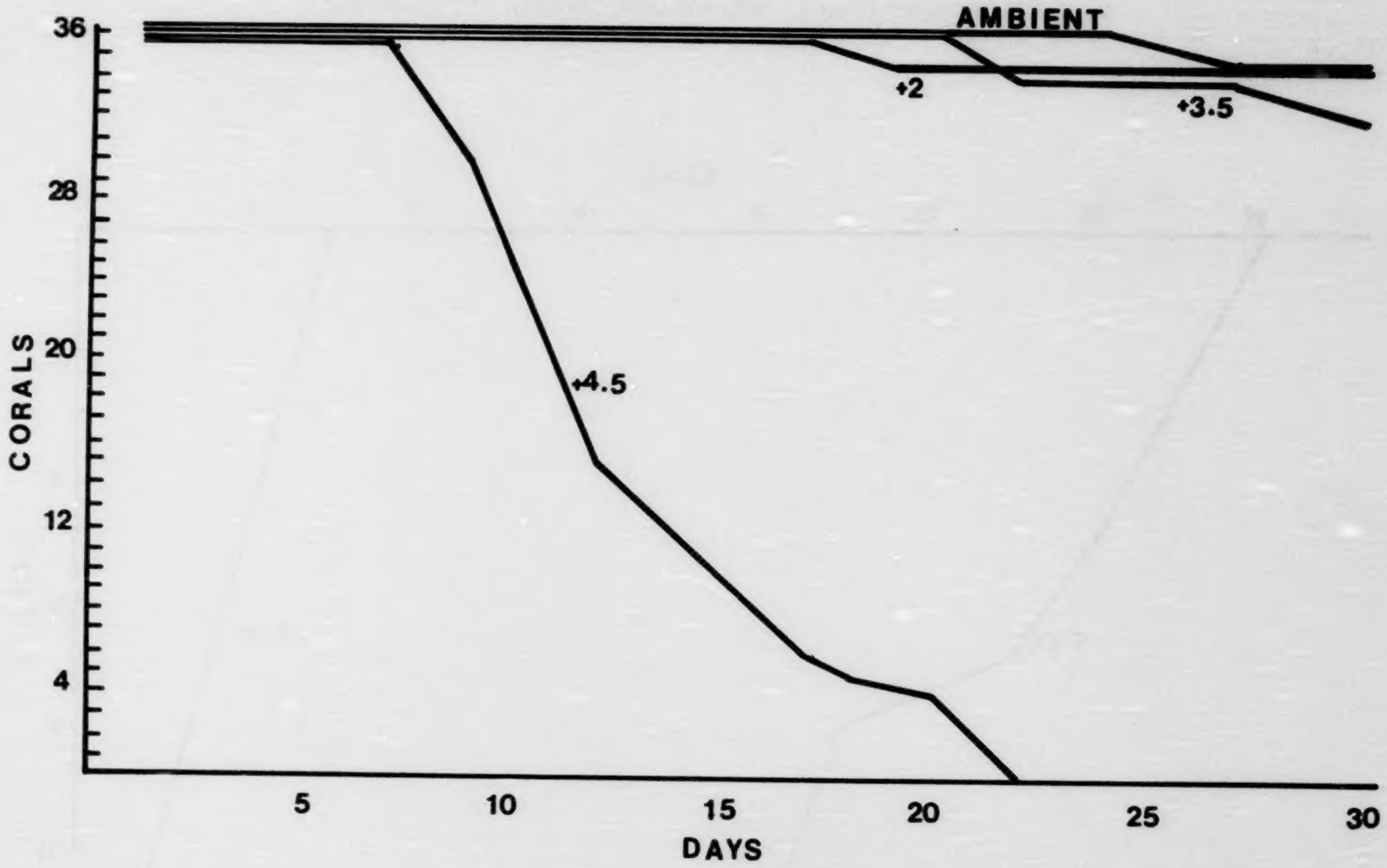

Figure 43 Acropora aspera

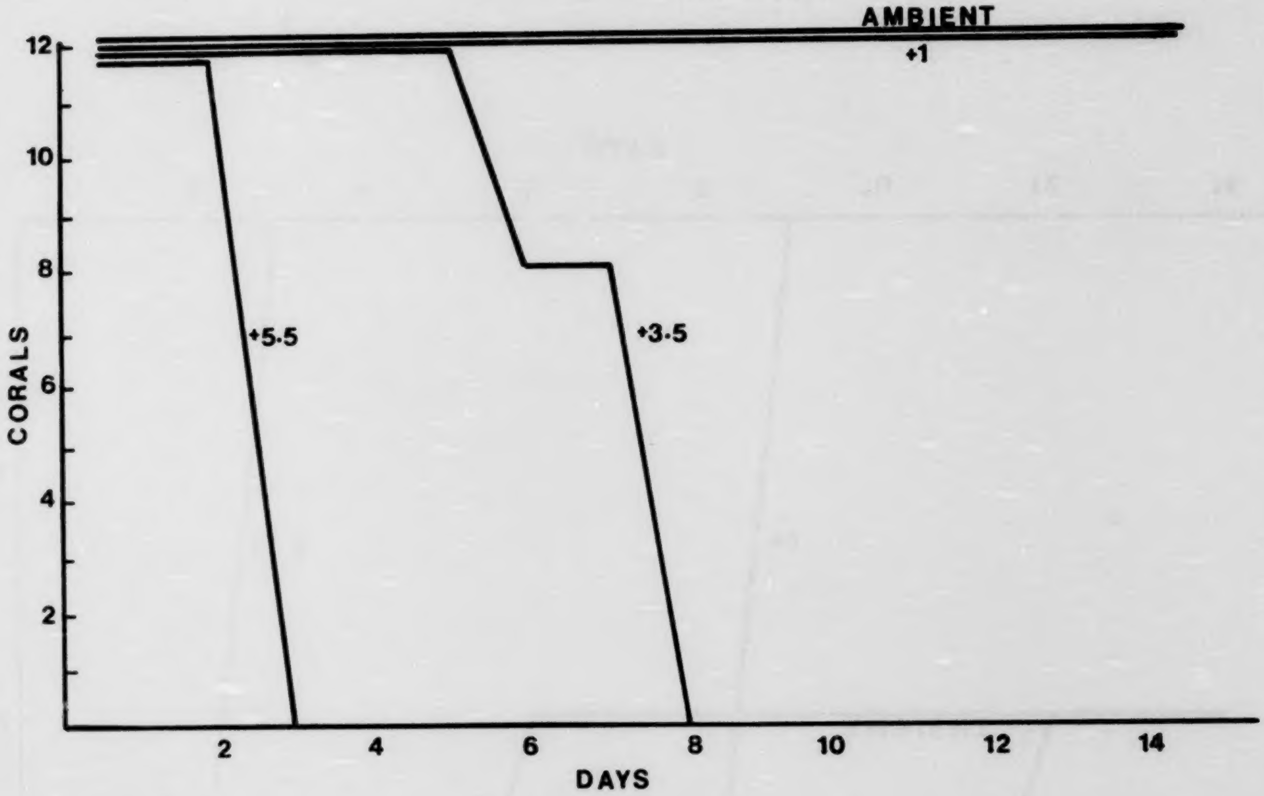

Figure 44 Acropora nasuta

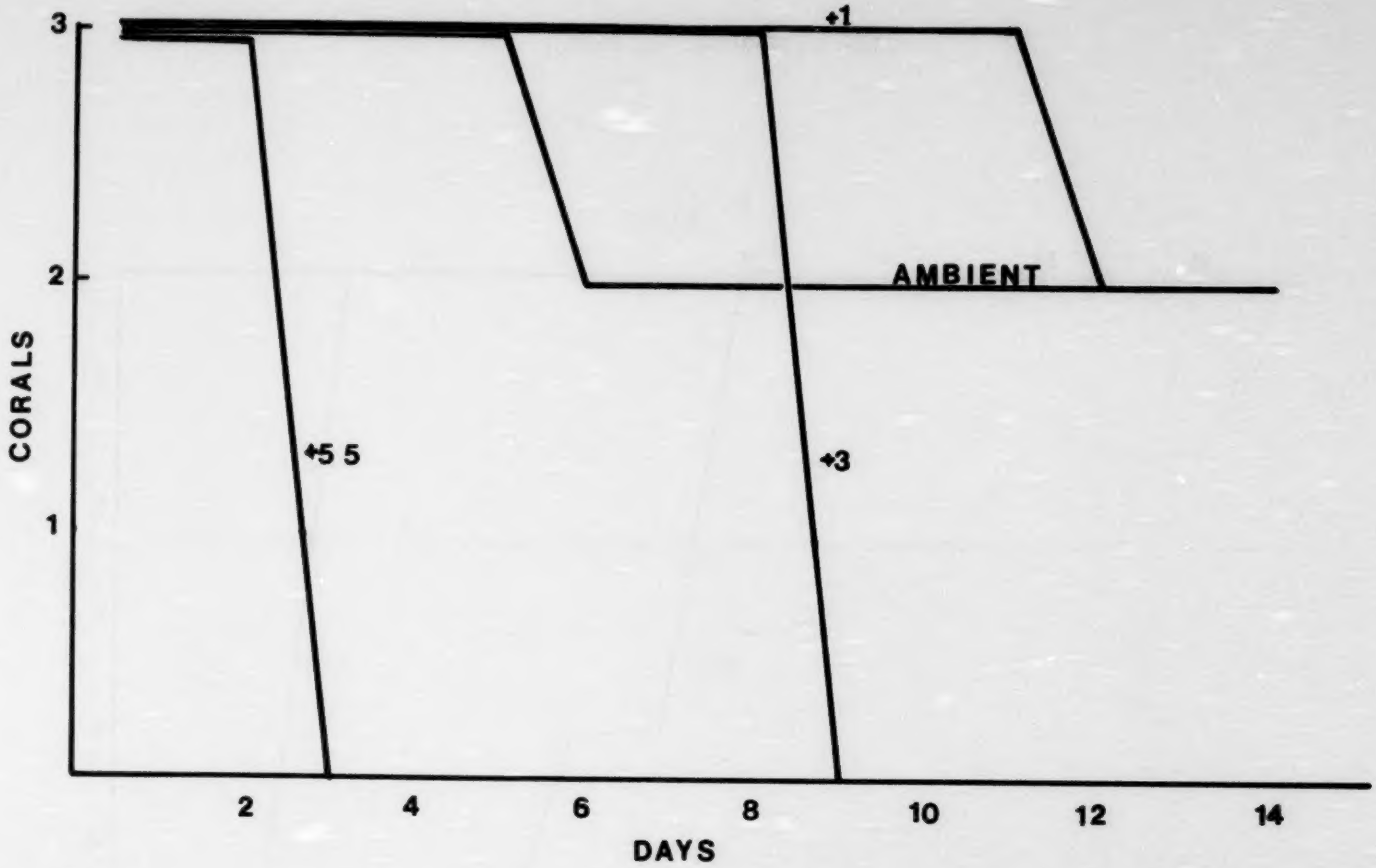

Figure 45 Acropora palifera

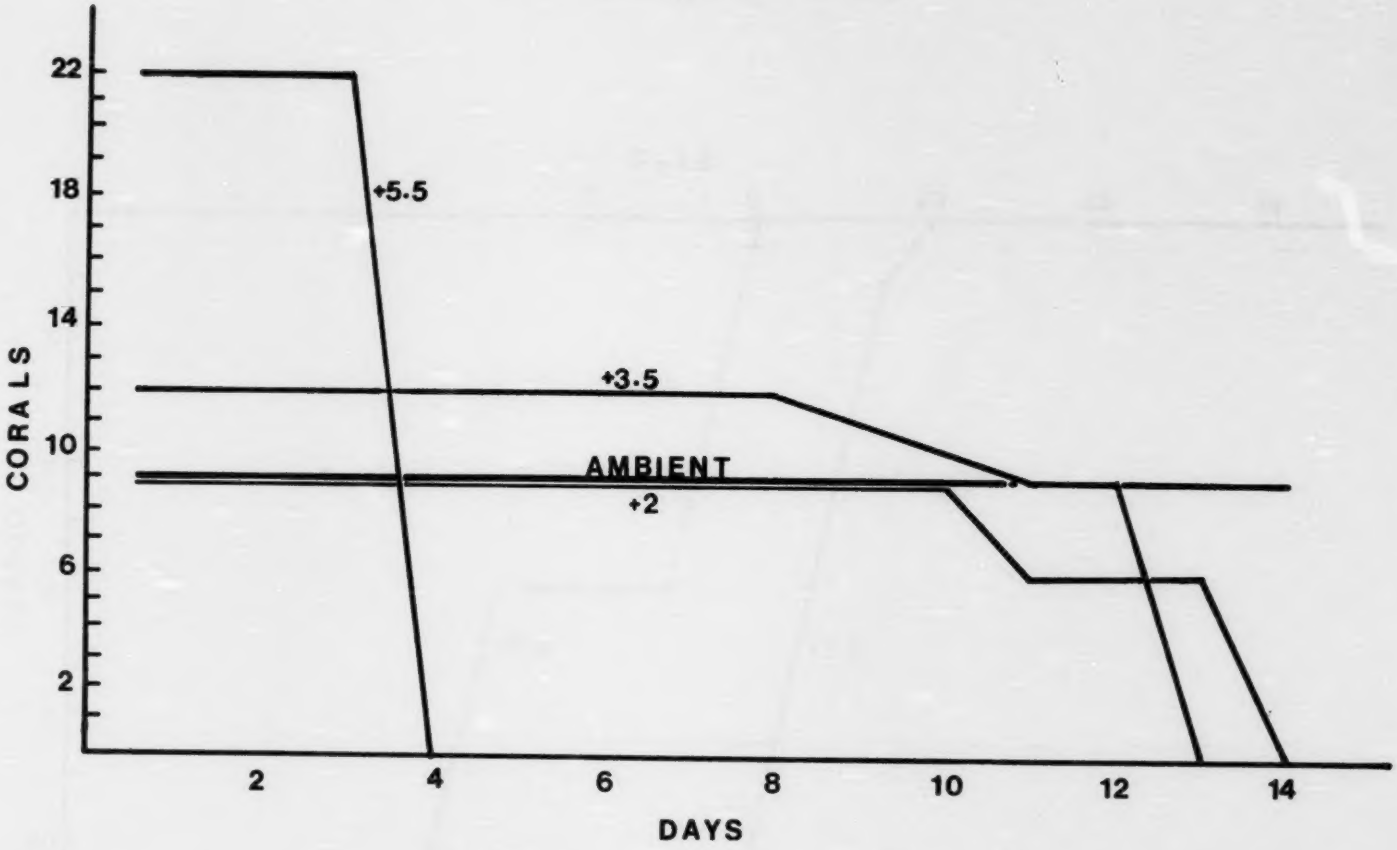

Figure 46 Leptoria phrygia

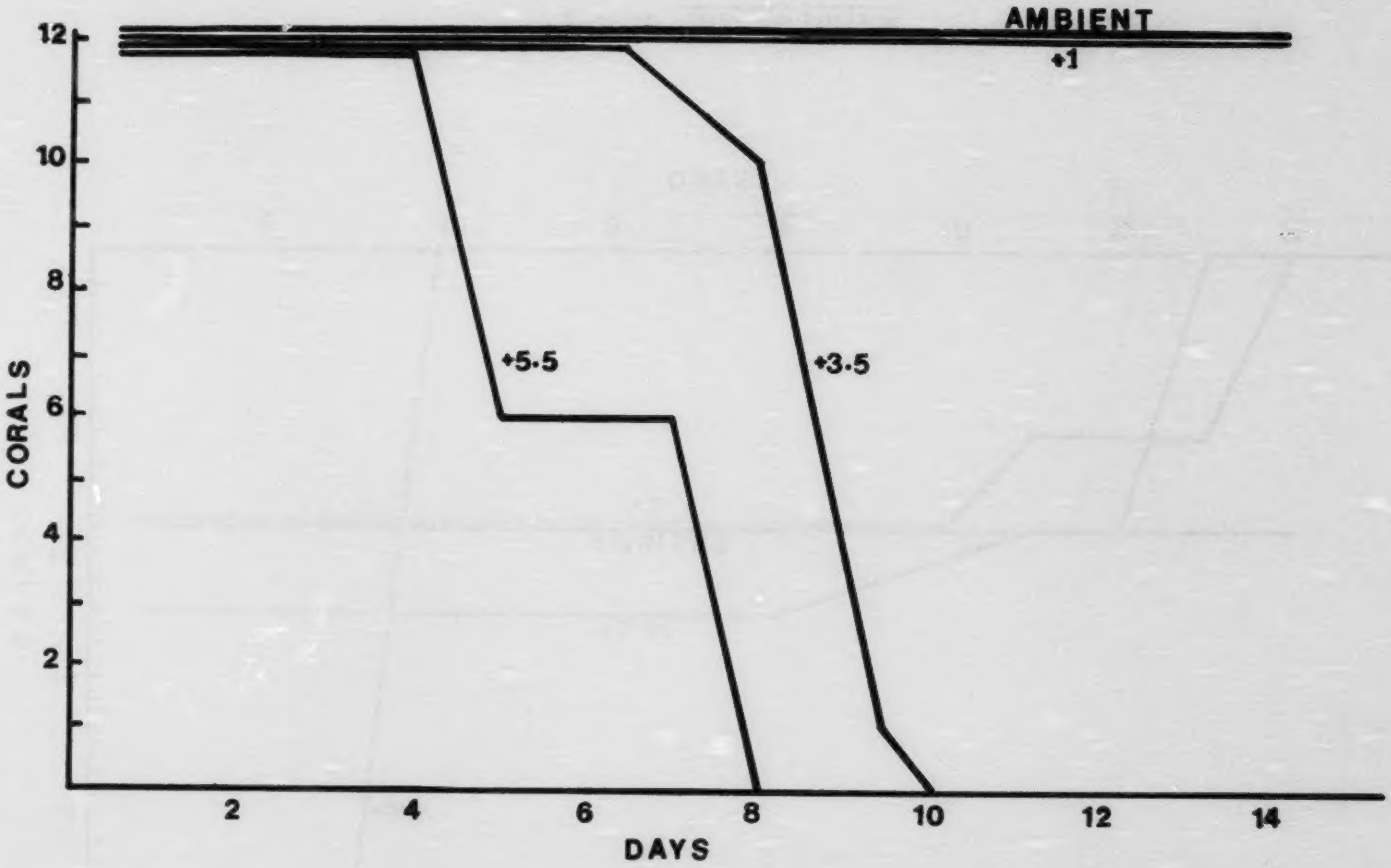

Figure 47 Millepora platyphylla

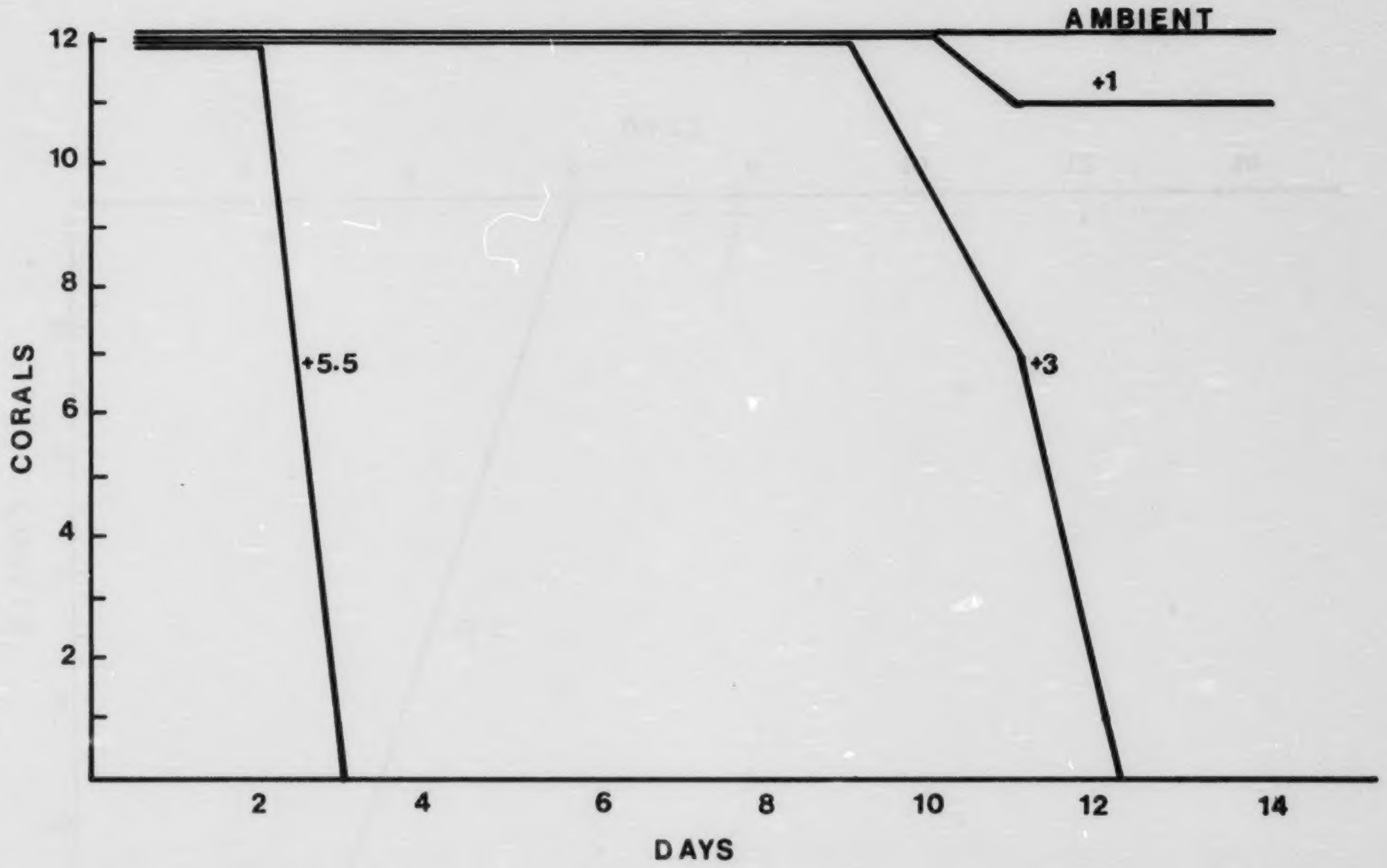

Figure 48 *Stylophora mordax*

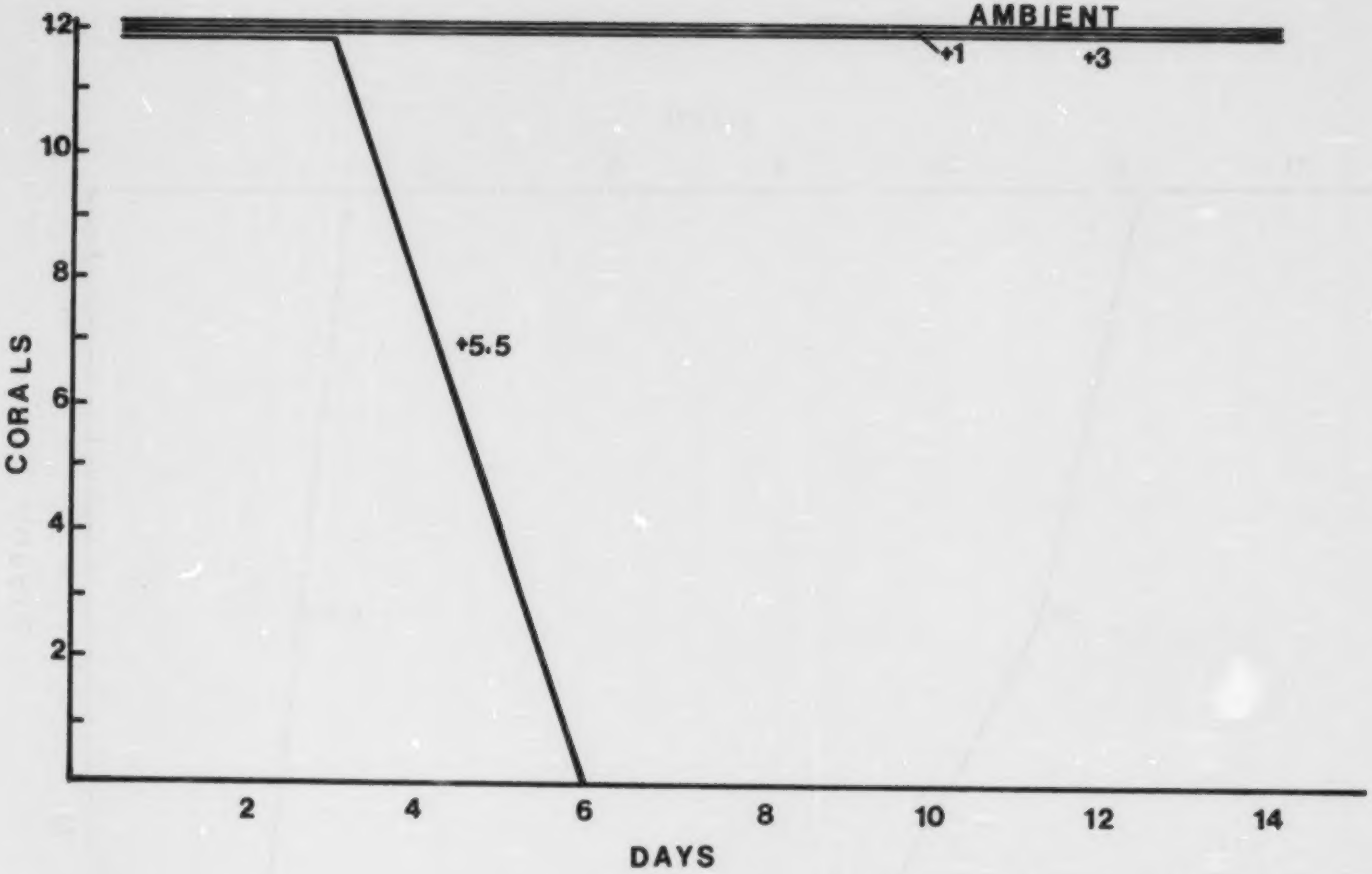

Figure 49 Platygyra rustica

reef margin opposite the power plant. Moreover, the field data presented in Section VIII verify the death of corals in situ.

Death of the corals was always proceeded by a loss in pigment that resulted in a bleaching of the polyps (Fig. 50). This response is identical to that reported in the field. Jokiel and Coles[11] have reported the same phenomenon in Hawaiian corals. Corals that survived in the control tanks and the +2°C tanks did not lose a significant amount of pigment.

Our data are too inconclusive to adequately support the hypothesis of Jokiel (personal communication) and his colleagues, which would suggest that Guam corals are adapted to higher temperatures than Hawaiian corals. However there is some evidence for a trend in this direction at least at the upper end (32°C Hawaii vs 33°C Guam).

Growth experiments were interesting but usually less striking than the preceeding. Corals (survivors) were weighed underwater, before and after the 14 to 30 day experimental periods. The weights were taken to the nearest 0.1g and corrected to dry weight using the following formula:

$$m = \frac{DcF}{Dc-Dw}$$

Where: m = dry weight of the coral
Dc = coral density (aragonite = 2.94)
Dw = density of seawater
F = underwater weight of the coral

The formula is thus based on the specific gravity of $CaCO_3$ (aragonite). When checked empirically, the results were found to be variable. Coral specimens were allowed to dry and were weighed in air. Next, the specimens were submersed for one to two weeks and then weighed underwater. When the formula was applied, deviations were evident. Kornicker and Squires[17] report that it may take up to eight months for porous coral skeletons to become completely saturated with water. It is the resulting difference between specific gravity of pure aragonite (2.94) and that forming complex coral skeletons that introduces the variability. Therefore the dry weight values given should be considered less than perfect.

Data for all specimens of each species had to be pooled and differences between weight in and weight out converted to percent gain in skeletal weight. These data are shown in Table 10. Pooling the data was unfortunate but necessary because coral growth was quite variable within experimental sample groups. This occurred because of differences in specimen sizes. Smaller specimens had faster growth rates than larger ones because of differences in ratio of total living tissue (coenosarc)

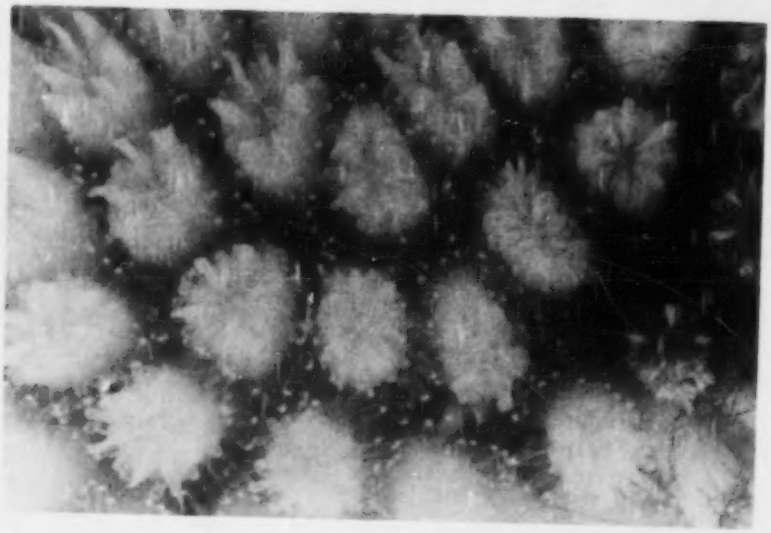

Figure 50 Bleached polyps of Galaxea hexagonalis

Figure 51 Transect B station showing anchor links and station number suspended by a float

Table 10. GROWTH OF CORALS AT EXPERIMENTAL TEMPERATURES.

X=corals failed to survive -=no data taken (-)=wt. loss	No. Experimental days	No. of Corals per test tank (X12)	Desired Experimental Temps. °C					
			28.5(Amb.)		30.5 (+2)		32.5 (+4)	
			Actual Temp	%wt. Gain	Actual Temp	%wt. Gain	Actual Temp	%wt. Gain
Psammocora contigua	14	18	28.0	22.0	30.0	17.0	32.0	(-)1.0
Porites lutea	30	18	28.0	20.0	30.0	16.0	32.0	(-)2.0
Pavona decussata	30	6	29.5	16.0	-	-	32.0	X
Pavona decussata	30	12	28.5	14.0	29.5	2.0	32.0	X
Platygyra rustica	14	12	29.5	12.0	29.5	15.0	31.5	6.5
Acropora palifera	14	3	28.0	11.0	29.5	18.2	32.0	6.0
Pocillopora setchelli	14	12	29.5	10.0	30.0	9.0	32.0	X
Acropora aspera	14	35	29.0	9.0	30.5	-	32.0	-
Acropora nasuta	14	12	28.5	8.5	29.5	0.2	32.0	X
Psammocora contigua	30	12	29.0	7.0	31.0	6.0	33.0	X
Pocillopora damicornis	30	12	29.0	7.0	31.0	5.0	33.0	X
Pocillopora damicornis	30	36	27.5	6.5	29.5	2.5	32.0	X
Pavona varians	30	9	28.0	3.3	30.5	2.2	32.5	X
Pavona frondifera	30	6	29.5	3.2	31.5	2.4	33.5	X
Galaxea hexagonalis	30	9	27.5	3.2	30.0	2.4	31.5	1.3
Galaxea hexagonalis	14	12	29.5	3.0	30.0	1.5	32.0	X
Leptoria phrygia	14	9	29.0	2.8	30.5	-	32.0	X
Porites lutea	30	6	29.0	2.7	31.0	2.9	33.0	X
Porites lutea	30	9	28.0	2.6	30.5	2.7	32.5	X
Favia stelligera	30	9	28.0	2.2	30.5	0.2	32.5	X
Pavona obtusata	30	9	28.0	2.0	30.5	2.6	32.0	1.6
Millepora platyphylla	14	12	28.5	1.8	29.5	0.3	32.0	X
Stylophora mordax	14	12	28.0	1.0	29.5	1.0	31.5	X
Fungia scutaria	30	12	29.0	0.4	31.0	1.0	33.0	X

areas to total weight of the corallum (cube/square ratio). These relationships and resultant growth rate differences are difficult to measure and control intraspecifically and virtually impossible interspecifically because of growth form and size differences in the coralla of the 18 species and 12 genera examined.

In spite of the inherent variability, there are some obvious trends of interest. No growth was recorded for specimens in the +6 (34.5°C) regime because all specimens normally died within three to ten days and before they had an adequate growth period.

Growth was observed in the +4 (32.5°C) tanks in only four cases, Platygira rustica, Galaxea hexagonalis, Pavona obtusata and Acropora palifera. In every case, there was a reduction in growth from both ambient and +2°C corals. In general, most of the specimens tested at +4°C failed to survive long enough to show measurable weight gains. Table 10 shows that corals that survived gained skeletal weight at the +2 (30.5°C) regime in every case where data are available. In 14 out of 21 tests, where data are available, weight gained was less than that recorded for ambient corals. In six of the tests, the weight gain in the +2 regime was greater than ambient. They were equal in only one case. For eight of the test samples, the differences in weight gained between ambient and +2 was 1.0% or less. In four of these eight, ambient gain was greater than +2 gains and in four, +2 gains were greater. Because of the considerable variability inherent in the measurement of weight, little significance should be attached to these eight tests.

Significant skeletal weight gain occurred in the ambient held specimens at temperatures between 27.5 and 29.5°C. This range includes growth at temperatures 1.0°C above summer ambient (28.5°C). Measurable skeletal weight gain also occurred between 29.5 and 31.5°C, 1.0 and 3.0°C above summer ambient. Growth was virtually eliminated above these ranges.

The general reduction in skeletal weight gain between ambient and +2°C clearly points out one of the elements of sublethal effects on hermatypic corals. Jokiel and Coles (personal communication) found the same sublethal effect as well as reduction in planula settlement in at least one species (Pocillopora damicornis).

SECTION X

EFFECTS OF ACANTHASTER PREDATION ON TANGUISSON CORALS

In February 1967, the coral eating "Crown-of-Thorns" starfish, *Acanthaster planci* (Linnaeus), was noted (Randall[12, 18]) in above normal population densities along local portions of the relatively sheltered northern half of Tumon Bay (Fig. 1). The infestation spread to Tanguisson Point located 2.4 kilometers north of Tumon Bay, sometime between June 1968, and September 1968. By April 1969, nearly all the starfish had migrated out of the Tanguisson area, leaving over 95 percent of the reef building (hermatypic) corals dead in the area seaward of the reef front zone.

OBJECTIVES

One of the grant objectives was a study of the damage to Tanguisson reefs, attributable to *Acanthaster*. This was to be completed prior to release of plant effluent in order to avoid confusion between environmental damage that might ultimately result from plant operations and that caused by *Acanthaster*. Unfortunately, the Tanguisson reef was destroyed prior to the start of the research and it was necessary to extrapolate about its pre-*Acanthaster* conditions from research on the nearby Tumon reef. A thorough study of coral distribution on the Tumon Bay fringing reef was conducted by Randall[12, 18] prior to the infestation of Guam by *Acanthaster planci* and before the grant research began. The Tumon reef is contiguous with the Tanguisson fringing reef and the two, except for the reef flat zones, were very similar in terms of coral species composition and distribution. Collections and observations were also made at Tanguisson by Randall[12, 18] during his 1966 to 1969 study of Tumon.

The second objective, regarding the *Acanthaster* damaged zones of the Tanguisson reef, was a study of potential coral recovery following intense predation. This natural catastrophe simulated a possible pollution-induced one and basic research on coral recovery and recolonization was done.

INITIAL ACANTHASTER DAMAGE (1968-1970)

Previous Work

Little previous work has been done on the fringing reefs of Guam with respect to coral distribution. Most studies are of a geological nature, dealing mainly with various physical parameters of the reef complex.

Some coral collections were made on Guam and Saipan by Cloud[19, 20], during U. S. geological surveys of these two islands. A list of coral genera was compiled from these collections by Wells[17]. Tracey et al[1], conducted several reef traverses in the study area. As far as could be determined, no systematic coral collections were made by them but several coral genera are listed by reef zones from "Reef Traverse 2, at Tumon Bay." The following genera were reported: from the reef margin-Acropora, Pocillopora, Favia, and Millepora; from the reef flat-Porites in the outer part, Acropora, Pavona, and Pocillopora in the inner part.

Other work on the reefs of Guam was done by Stearns[21], Cloud[22], and Tayama[23]. Coral distribution was not included in these studies. A study of the marine geology of Guam by Emery[2] includes investigations of submarine slopes, lagoon floors, channels through fringing reefs, beaches, and rocky shores.

Observations on Acanthaster were first reported by Chesher[15]. Chesher describes A. planci population movements, densities, feeding behaviour, relative coral predation rates, control measures, and possible causative factors related to the sudden increase in numbers of starfish in various Indo-Pacific regions. Tsuda[24] describes the current status of A. planci on Guam with regard to population densities, location of infested reefs, and the extent of the coral damage.

Methods

Three permanent Transects (A, B, and C), were established at Tanguisson Point. Figure 3 shows the location of these transects. Stations were established at 10 m intervals along the transects from the upper intertidal zone to a depth of 30 m on the seaward slope. These station locations were permanently marked by placing three to five links of ship anchor chain (4.7 kg per link) at each. Stations were identified by attaching numbered fiberglass cards to the anchor chain links. For ease in locating the transect stations, the numbered cards were suspended approximately 0.5 m above the anchor links by a plastic float (Fig. 51). At each station a reference point was established at the point where the numbered card was attached to the anchor links.

Two wire grid quadrats, each one meter square, were positioned at the station reference point (Fig. 52). After positioning of the quadrat grids, the following data were recorded from each: (1) the transect station number; (2) the quadrat number; and (3) the specific name, size, and growth form of each living coral found within the confines of the grid. The various coral growth forms differentiated follow those described by Wells[25]. A columnar form was added which differentiates an intermediate mode of development between the massive and ramose forms. A subdivision of ramose forms into corymbose, cespitose, and arborescent modes of branching was made.

The diameter of individual coral colonies was measured with a meter stick with moveable trammel points. If circular, the colony diameter measurement was made at the widest point across the corallum. If the colony shape was not circular, its outline was sketched and several measurements of length and width were recorded.

Distribution of Corals

Coral distribution at Tanguisson Point is based upon data from the three transects, general field observations, and specimen collections. Extensive systematic coral collections were not made at the Tanguisson study region because a similar species composition was collected at Tumon Bay (Randall[12]). The only corals collected at Tanguisson Point were those that could not be identified in the field, those that represented new growth forms, or those that were not previously collected at Tumon Bay. Field work for the study was started at Tanguisson during September 1969, and was continued until July 1970. Table 11 lists the coral species known from the study area.

Table 12 lists the frequency distribution of coral species observed on the transects by reef zones. This table shows that 86 species representing 30 genera occurred on the three transects. Combining this with the number of species shown on Table 11 that did not occur on the transects, the total number of species is raised to 96 representing 33 genera. From the total number of species and genera occurring at Tanguisson Point, 91 species represented by 30 genera are hermatypic, scleractinians and the remaining five species representing three genera are nonscleractinians. No ahermatypic corals were observed or collected at Tanguisson Point, even though investigations were made to depths of 35 m.

Intertidal (5 to 10 m wide)-- In most places the intertidal zone is either bare reef-rock, sand, or an irregular raised strip of solution-pitted limestone (Fig. 2).

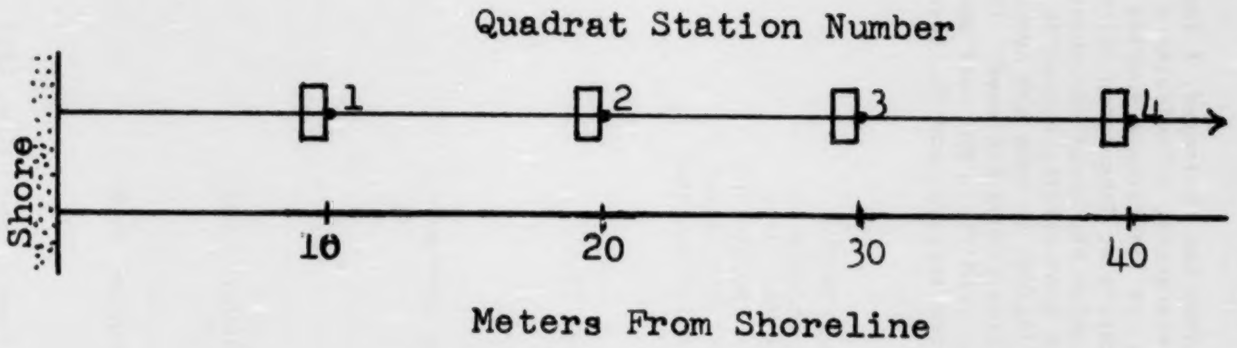
Quadrat Station Number
1
2
3
4
Shore
10
20
30
40
Meters From Shoreline

Figure 52 Diagram of the station quadrat transect method

Table 11. CHECKLIST OF CORALS THAT WERE OBSERVED ON THE TRANSECTS AND COLLECTED FROM TANGUISSON POINT.

[* indicates that the specimen was collected, # indicates a species observed on the transects, + indicates a species observed in the study area, ++ indicates a species which was identified from dead corals at Tanguisson Point. The locality and reef zone in which the coral was observed or collected (University of Guam catalog number is included if specimen was collected) follows the symbol. The following-reef zone abbreviations are used: IRF, inner reef flat; ORF, outer reef flat; RM, reef margin; RF, reef front; ST, submarine terrace; and SS, seaward slope.]

Class ANTHOZOA
Subclass Zoantharia
Order SCLERACTINIA
Suborder ASTROCOENIINA
Family ASTROCOENIIDAE
Subfamily ASTROCOENIINAE

Genus Stylocoeniella
- Stylocoeniella armata (Ehrenberg, 1834)
  - *Tanguisson Point - 1555, RF
  - #Tanguisson Point - RF, ST, SS

Family THAMNASTERIIDAE

Genus Psammocora
- Psammocora exesa Dana, 1846
  - #Tanguisson Point - RF
  - ++Tanguisson Point - SS
- Psammocora nierstraszi van der Horst, 1921
  - #Tanguisson Point - RM, RF, ST

Sugbenus Stephanaria
- Psammocora (S.) togianensis Umbgrove, 1940
  - ++Tanguisson Point - SS

Subgenus Plesioseris
- Psammocora (P.) haimeana Milne Edwards and Haime, 1851
  - #Tanguisson Point - SS

Table 11. (continued).

Family POCILLOPORIDAE

- Genus *Stylophora*
  - *Stylophora mordax* (Dana, 1846)
    - #Tanguisson Point - RF, ST
- Genus *Pocillopora*
  - *Pocillopora eydouxi* Milne Edwards and Haime, 1960
    - #Tanguisson Point - RF
    - +Tanguisson Point - ST
  - *Pocillopora ligulata* Dana, 1846
    - *Tanguisson Point - 1599, 1600, RF
  - *Pocillopora meandrina* Dana, 1846
    - #Tanguisson Point - ORF, RM, RF
  - *Pocillopora setchelli* Hoffmeister, 1929
    - #Tanguisson Point - RM
  - *Pocillopora verrucosa* (Ellis and Solander, 1786)
    - #Tanguisson Point - RM, RF, ST, SS
  - *Pocillopora* sp. 1
    - #Tanguisson Point - ORF, RF, ST

Family ACROPORIDAE

- Genus *Acropora*
  - *Acropora abrotanoides* (Lammarck, 1816)
    - #Tanguisson Point - RF
  - *Acropora humilis* (Dana, 1846)
    - #Tanguisson Point - RF, SS
  - *Acropora hystrix* (Dana, 1846)
    - *Tanguisson Point - 1550, RF
    - #Tanguisson Point - RM, RF
  - *Acropora kenti* (Brook, 1892)
    - +Tanguisson Point - ST, SS
  - *Acropora murrayensis* Vaughan, 1918
    - #Tanguisson Point - RM, RF
  - *Acropora nana* (Studer, 1879)
    - *Tanguisson Point - 1549, RF
    - #Tanguisson Point - RM, RF
  - *Acropora nasuta* (Dana, 1846)
    - #Tanguisson Point - RM, RF

Table 11. (continued).

- Acropora ocellata (Klunzinger, 1879)
  - *Tanguisson Point - 1559, 1560, 1561, 1562, RF
- Acropora palifera (Lammarck, 1816)
  - ++Tanguisson Point - SS
- Acropora palmerae Wells, 1954
  - #Tanguisson Point - RM, RF
- Acropora rambleri (Bassett Smith, 1890)
  - ++Tanguisson Point - SS
- Acropora rayneri (Brook, 1892)
  - ++Tanguisson Point - RF
- Acropora smithi (Brook, 1893)
  - #Tanguisson Point - RM, RF
- Acropora squarrosa (Ehrenberg, 1834)
  - *Tanguisson Point - 1553, 1557, RF
- Acropora studeri (Brook, 1893)
  - #Tanguisson Point - RF, ST
- Acropora surculosa (Dana, 1846)
  - #Tanguisson Point RF, ST
- Acropora syringodes (Brook, 1892)
  - *Tanguisson Point - 1551, 1552, 1563, 1564, RF
- Acropora valida (Dana, 1846)
  - #Tanguisson Point - RF
- Acropora sp. 1
  - #Tanguisson Point - RF

- Genus Astreopora
  - Astreopora gracilis Bernard, 1896
    - #Tanguisson Point - RF, ST
  - Astreopora myriophthalma (Lammarck, 1816)
    - #Tanguisson Point - ST

- Genus Montipora
  - Montipora conicula Wells, 1954
    - #Tanguisson Point - RF
  - Montipora elschneri Vaughan, 1918
    - #Tanguisson Point - RF
  - Montipora foveolata (Dana, 1846)
    - #Tanguisson Point - RF, ST
  - Montipora granulosa Bernard, 1897
    - #Tanguisson Point - RF
  - Montipora hoffmeisteri Wells, 1954
    - #Tanguisson Point - RF
  - Montipora monasteriata (Forskaal, 1775)
    - #Tanguisson Point - RF

Table 11. (continued).

- *Montipora tuberculosa* (Lammarck, 1816)
  - #Tanguisson Point - ST
- *Montipora verrilli*Vaughan, 1907
  - #Tanguisson Point - RM, RF, ST, SS
- *Montipora* sp. 1
  - #Tanguisson Point - RF, ST, SS
- *Montipora* sp. 2
  - #Tanguisson Point - ST
- *Montipora* sp. 3
  - #Tanguisson Point - RF, ST
- *Montipora* sp. 4
  - #Tanguisson Point - RF
- *Montipora* sp. 5
  - #Tanguisson Point - RF, ST

Suborder FUNGIINA
Superfamily AGARCIICAE
Family AGARICCIIDAE

Genus *Pavona*

- *Pavona clavus* (Dana, 1846)
  - #Tanguisson Point - RF, ST
- *Pavona varians* Verrill, 1864
  - #Tanguisson Point - RF, ST

Subgenus *Pseudocolumnastraea*

- *Pavona (P.) pollicata* Wells, 1954
  - #Tanguisson Point - RF

Subgenus *Polyastra*

- *Pavona (P.)* sp. 3
  - #Tanguisson Point - RF, SS

Genus *Leptoseris*

- *Leptoseris hawaiiensis* Vaughan, 1907
  - #Tanguisson Point - SS

Genus *Pachyseris*

- *Pachyseris speciosa* (Dana, 1846)
  - +Tanguisson Point - SS
  - ++Tanguisson Point - SS

Table 11. (continued).

Family SIDERASTREIDAE

Genus *Coscinaraea*
Coscinaraea columna (Dana, 1846)
#Tanguisson Point - RM
++Tanguisson Point - SS

Superfamily FUNGIICAE
Family FUNGIIDAE

Genus *Cycloseris*
Cycloseris cyclolites (Lammarck, 1816)
*Tanguisson Point - 1568, ST
#Tanguisson Point - SS
Cycloseris sp. 1
#Tanguisson Point - ST

Superfamily PORITICAE
Family PORITIDAE

Genus *Goniopora*
Goniopora columna Dana, 1846
#Tanguisson Point - ST, SS
Goniopora sp. 1
++Tanguisson Point - SS

Genus *Porites*
Porites australiensis Vaughan, 1918
#Tanguisson Point - RF, ST
Porites lobata Dana, 1846
#Tanguisson Point, 1846
Porites lutea Milne Edwards and Haime, 1851
#Tanguisson Point - RM, RF, ST, SS
Porites sp. 1
*Tanguisson Point - 1648, RF
#Tanguisson Point - RM, RF, SS
Porites sp. 2
*Tanguisson Point - 1490, 1491, SS

Table 11. (continued)

- Subgenus *Synaraea*
  - *Porites* (*S.*) *convexa* Verrill, 1864
    - +Tanguisson Point - SS
  - *Porites* (*S.*) *hawaiiensis* Vaughan, 1907
    - #Tanguisson Point - SS
  - *Porites* (*S.*) *horizontalata* Hoffmeister, 1925
    - #Tanguisson Point - SS
  - *Porites* (*S.*) *iwayamaensis* Eguchi, 1938
    - #Tanguisson Point - ST, SS

- Genus *Alveopora*
  - *Alveopora verrilliana* Dana, 1872
    - *Tanguisson Point - 1570, ST

Suborder FAVIINA
Superfamily FAVIICAE
Family FAVIIDAE
Subfamily FAVIINAE

- Genus *Favia*
  - *Favia favus* (Forskaal, 1775)
    - #Tanguisson Point - RF, ST
  - *Favia pallida* (Dana, 1846)
    - #Tanguisson Point - RM, RF, ST, SS
  - *Favia stelligera* (Dana, 1846)
    - #Tanguisson Point - RM, RF, ST
  - *Favia rotumana* (Gardiner, 1889)
    - #Tanguisson Point - ST

- Genus *Favites*
  - *Favites complanata* (Ehrenberg, 1834)
    - *Tanguisson Point - 1601, ST
    - #Tanguisson Point - RF, ST, SS
  - *Favites favosa* (Ellis and Solander, 1786)
    - #Tanguisson Point - ST
  - *Favites flexuosa* (Dana, 1846)
    - #Tanguisson Point - SS

- Genus *Plesiastrea*
  - *Plesiastrea versipora* (Lammarck, 1816)
    - *Tanguisson Point - 1639, RM
    - #Tanguisson Point - RM, RF
    - ++Tanguisson Point - SS

Table 11. (continued)

Genus *Goniastrea*
Goniastrea parvistella (Dana, 1846)
#Tanguisson Point - RF, ST
Goniastrea pectinata (Ehrenberg, 1831)
#Tanguisson Point - ST, SS
Goniastrea retiformis (Lammarck, 1816)
#Tanguisson Point - RM, RF, ST

Genus *Platygyra*
Platygyra rustica (Dana, 1846)
#Tanguisson Point - RF, ST
Platygyra sinensis (Milne Edwards and Haime, 1849)
*Tanguisson Point - 1568, RF
#Tanguisson Point - RF, ST

Genus *Leptoria*
Leptoria gracilis (Dana, 1846)
*Tanguisson Point - 1603, 1647, RF
#Tanguisson Point - RM, RF, ST
Leptoria phrygia (Ellis and Solander, 1786)
+Tanguisson Point - RM, RF, ST
#Tanguisson Point - RM, RF, ST

Genus *Hydnophora*
Hydnophora microconos (Lammarck, 1816)
#Tanguisson Point - RF
++Tanguisson Point - SS

Subfamily MONTASTREINAE

Genus *Leptastrea*
Leptastrea purpurea (Dana, 1846)
#Tanguisson Point - RF, ST, SS
Leptastrea transversa (Klunzinger, 1879)
*Tanguisson Point - 1571-1, RF
#Tanguisson Point - ST, SS
Leptastrea sp. 1
#Tanguisson Point - RF, SS

Table 11. (continued)

Genus Cyphastrea
  Cyphastrea chalcidicum (Forskaal, 1775)
    #Tanguisson Point - RF, SS
  Chyphastrea serailia (Forskaal, 1775)
    #Tanguisson Point - RF
    ++Tanguisson Point - SS

Genus Echinopora
  Echinopora lamellosa (Esper, 1787)
    #Tanguisson Point - RF, SS

Genus Diploastrea
  Diploastrea heliopora (Lammarck, 1816)
    +Tanguisson Point - ST, SS

Family OCULINIDAE
Subfamily GALAXEINAE

Genus Galaxea
  Galaxea fascicularis (Linnaeus, 1758)
    #Tanguisson Point - RF, ST, SS
  Galaxea hexagonalis Milne,Edwards and Haime, 1857
    #Tanguisson Point - RF, ST, SS

Family MUSSIDAE

Genus Lobophyllia
  Lobophyllia corymbosa (Forskaal, 1775)
    #Tanguisson Point - SS
  Lobophyllia costata (Dana, 1846)
    #Tanguisson Point - RF, ST

Genus Acanthastrea
  Acanthastrea echinata (Dana, 1846)
    *Tanguisson Point - 1645, RF
    #Tanguisson Point - RF, ST

Table 11. (continued)

Family PECTINIIDAE

- Genus *Echinophyllia*
  - *Echinophyllia asper* Ellis and Solander, 1786
    - #Tanguisson Point - SS

Subclass OCTOCORALLIA
Order COENOTHECALIA
Family HELIOPORIDAE

- Genus *Heliopora*
  - *Heliopora coerulea* (Pallas, 1766)
    - #Tanguisson Point - ST

Class HYDROZOA
Order MILLEPORINA
Family MILLEPORIDAE

- Genus *Millepora*
  - *Millepora dichotoma* Forskaal, 1775
    - #Tanguisson Point - RF
    - +Tanguisson Point - ST
  - *Millepora exaesa* Forskaal, 1775
    - #Tanguisson Point - RF, ST
  - *Millepora platyphylla* Hemprich and Ehrenberg, 1834
    - #Tanguisson Point - RM, RF
    - +Tanguisson Point - ST

Order STYLASTERINA
Family STYLASTERIDAE
Subfamily DISTICHOPORINAE

- Genus *Distochopora*
  - *Distochopora violacea* (Pallas, 1776)
    - #Tanguisson Point - RM

Table 12. RELATIVE FREQUENCY OF OCCURRENCE AND ZONAL DISTRIBUTION OF CORALS AT TANGUISSON POINT. Relative frequency of occurrence is expressed as a percentage of the total number of colonies found in a transect zone or combination of zones. Data from Transects A, B and C are combined. The species are listed in order of decreasing frequency when all zones are combined.

Name of Coral	Reef margin		Reef front		Submarine terrace		Seaward slope		All Zones combined	
	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %
Galaxea hexagonalis	---	---	94	15.03	13	4.06	1	.62	108	8.29
Goniastrea retiformis	10	5.52	69	10.92	8	2.50	---	---	87	6.68
Favia stelligera	11	6.08	39	6.17	20	6.25	---	---	70	5.38
Montipora verrilli	12	6.63	31	4.91	10	3.13	12	7.45	65	4.49
Pavona varians	---	---	13	2.06	39	12.19	---	---	52	3.99
Favia pallida	3	1.66	18	2.85	18	5.63	12	7.45	51	3.92
Porites lutea	5	2.76	9	1.42	17	5.31	17	10.56	48	3.69
Pocillopora verrucosa	12	6.63	21	3.32	8	2.50	1	.62	42	3.23
Acropora nana	14	7.73	23	3.64	---	---	---	---	37	2.84
Pocillopora meandrina	15	8.29	15	2.37	---	---	---	---	34	2.61
Acanthastrea echinata	---	---	24	3.80	9	2.81	---	---	33	2.53
Leptoria gracilis	8	4.42	20	3.16	5	1.56	---	---	33	2.53
Leptastrea purpurea	---	---	4	.63	16	5.00	12	7.45	32	2.46
Leptoria phrygia	5	2.76	16	2.53	9	2.81	---	---	30	2.30
Porites sp. 1	14	7.73	10	1.58	---	---	1	.62	29	2.23
Millepora platyphylla	14	7.73	9	1.42	---	---	---	---	23	1.77
Pocillopora setchelli	12	6.63	11	1.74	---	---	---	---	23	1.77
Stylocoeniella armata	---	---	8	1.27	4	1.25	10	6.21	22	1.69
Montipora sp. 1	---	---	6	.95	6	1.88	7	4.35	19	1.46
Galaxea fascicularis	---	---	4	.63	6	1.88	8	4.97	18	1.38
Pavona clavus	---	---	10	1.58	8	2.50	---	---	18	1.38
Acropora hystrix	8	4.42	9	1.42	---	---	---	---	17	1.31
Favites complanata	---	---	6	.95	6	1.88	5	3.11	17	1.31
Goniastrea parvistella	---	---	6	.95	11	3.44	---	---	17	1.31
Leptastrea transversa	---	---	---	---	4	1.25	13	8.07	17	1.31
Plesiastrea versipora	7	3.87	10	1.58	---	---	---	---	17	1.31
Acropora nasuta	10	5.52	6	.95	---	---	---	---	16	1.23
Porites (Synaraea) iwayamaensis	---	---	---	---	4	1.25	12	7.45	16	1.23

Table 12. (continued)

Name of Coral	Reef margin		Reef front		Submarine terrace		Seward slope		All Zones combined	
	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %
Psammocora nierstraszi	3	1.66	10	.58	3	.94	---	---	16	1.23
Millepora exaesa	---	---	5	.79	10	3.13	---	---	15	1.15
Leptastrea sp. 1	---	---	1	.16	---	---	13	8.07	14	1.08
Porites lobata	---	---	4	.63	10	3.13	---	---	14	1.08
Stylophora mordax	---	---	8	1.27	5	1.56	---	---	13	1.00
Acropora murrayensis	8	4.42	4	.63	---	---	---	---	12	.92
Acropora studeri	---	---	6	.95	5	1.56	---	---	11	.84
Goniastrea pectinata	---	---	---	---	8	2.50	1	1.86	11	.84
Favia favus	---	---	4	.63	6	1.88	---	---	10	.76
Montipora elschneri	---	---	8	1.27	2	.63	---	---	10	.76
Acropora surculosa	---	---	7	1.11	2	.63	---	---	9	.69
Platygyra rustica	---	---	6	.95	3	.94	---	---	9	.69
Acropora humilis	---	---	5	.79	---	---	3	1.86	8	.61
Montipora foveolata	---	---	4	.63	4	1.25	---	---	8	.61
Montipora sp. 3	---	---	8	1.27	---	---	---	---	8	.61
Platygyra sinensis	---	---	5	.79	3	.94	---	---	8	.61
Porites australiensis	---	---	3	.47	5	1.56	---	---	8	.61
Acropora abrotanoides	---	---	7	1.11	---	---	---	---	7	.54
Pavona (Polyastra) sp. 3	---	---	4	.63	---	---	3	1.86	6	.46
Cyphastrea chalcidicum	---	---	4	.63	---	---	2	1.24	6	.46
Lobophyllia costata	---	---	4	.63	2	.63	---	---	6	.46
Montipora sp. 2	---	---	---	---	6	1.88	---	---	6	.46
Acropora palmerae	4	2.21	1	.16	---	---	---	---	5	.38
Distochopora violacea	5	2.76	---	---	---	---	---	---	5	.38
Echinopora lamellosa	---	---	2	.32	---	---	3	1.86	5	.38
Montipora sp. 4	---	---	5	.79	---	---	---	---	5	.38
Montipora sp. 5	---	---	1	.16	4	1.25	---	---	5	.38
Pocillopora sp. 1	---	---	1	.16	4	1.25	---	---	5	.38
Psammocora (Plesioseris) haimeana	---	---	---	---	---	---	5	3.11	5	.38
Astreopora gracilis	---	---	1	.16	3	.94	---	---	4	.31
Lobophyllia corymbosa	---	---	---	---	---	---	4	2.48	4	.31
Acropora smithi	---	---	3	.47	---	---	---	---	3	.23

Table 12. (continued)

Name of Coral	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %	No.	Rel. %
Astreopora myriophthalma	---	---	---	---	3	.94	---	---	3	.23
Cycloseris cycloties	---	---	---	---	---	---	3	1.86	3	.23
Echinophyllia aspera	---	---	---	---	---	---	3	1.86	3	.23
Coniopora columna	---	---	---	---	1	.31	2	1.24	3	.23
Leptoseris hawaiiensis	---	---	---	---	---	---	3	1.86	3	.23
Montipora conicula	---	---	3	.47	---	---	---	---	3	.23
Montipora monasteriata	---	---	3	.47	---	---	---	---	3	.23
Montipora tuberculosa	---	---	---	---	3	.94	---	---	3	.23
Acropora valida	---	---	2	.32	---	---	---	---	2	.15
Cycloseris sp. 1	---	---	---	---	2	.63	---	---	2	.15
Favia rotumana	---	---	---	---	2	.63	---	---	2	.15
Favites favosa	---	---	---	---	2	.63	---	---	2	.15
Montipora granulosa	---	---	2	.32	---	---	---	---	2	.15
Pocillopora eydouxi	---	---	2	.32	---	---	---	---	2	.15
Psammocora exesa	---	---	2	.32	---	---	---	---	2	.15
Acropora sp. 1	---	---	1	.16	---	---	---	---	1	.07
Coscinaraea columna	1	.53	---	---	---	---	---	---	1	.07
Cyphastrea serailia	---	---	1	.16	---	---	---	---	1	.07
Favites flexuosa	---	---	---	---	---	---	1	.62	1	.07
Heliopora coerulea	---	---	---	---	1	.31	---	---	1	.07
Hydnophora microconos	---	---	1	.16	---	---	---	---	1	.07
Millepora dichotoma	---	---	1	.16	---	---	---	---	1	.07
Montipora hoffmeisteri	---	---	1	.16	---	---	---	---	1	.07
Pavona (Pseudocolumnastraea) pollicata	---	---	1	.16	---	---	---	---	1	.07
Porites (Synaraea) hawaiiensis	---	---	---	---	---	---	1	.62	1	.07
Porites (Synaraea) horizontalata	---	---	---	---	---	---	1	.62	1	.07
Totals	181		632		320		161		1302	
Total species	21		65		45		28		86	
Total genera	12		24		22		19		30	

Reef Flat (70 to 100 m wide)-- The fringing reef platform along Tanguisson Point is divided into inner and outer reef flat subzones, but the inner reef flat is very poorly developed. At low tide the impounded water or moat, which delineates the inner reef flat subzone, represents a very small percentage of the reef platform and is not contiguous along the entire study region (Fig. 3). The inner reef flat subzone is represented by several small pools (Fig. 3) at Transects A and C. No corals occurred on the transects, but several small colonies of Porites lutea were observed in a small pool near Transect C. The outer reef flat subzone is, in most places, a flat limestone pavement with very little relief. Only eight colonies of corals were encountered on the transects. One each of Pocillopora meandrina and Porites lutea and six of Acropora nana. These colonies were found occupying shallow pools near the reef margin zone. Coral observations along other parts of the outer reef flat are similar to those found near the transect regions.

Reef Margin (20 m wide)-- This zone is awash constantly and represents conditions favorable for coral development. Figures 53 and 54 reflect this change in habitat by abrupt increases in the percentage of reef surface covered by living corals and number of species and genera per transect station.

The reef margin environment can be divided into three separate habitats: the well-lighted, strongly-agitated water region found on the upper surface of buttresses that separate surge channels; the open surge channels and pools; and the poorly-lighted, cavernous regions of surge channels and pools. On the upper surface of the buttresses (Fig. 55), the most common corals were: Acropora palmerae; Goniastrea retiformis; Millepora platyphylla; Pocillopora meandrina, P. setchelli, and P. verrucosa. In the surge channels and open pools habitats the more common corals encountered were: Acanthastrea echinata; Acropora hystrix, A. murrayensis, A. nana, A. nasuta; Favia pallida, F. stelligera; Favites abdita; Goniastrea retiformis; Leptoria gracilis, L. phrygia; Montipora verrilli; Millepora platyphylla; Plesiastrea versipora; Pocillopora verrucosa, P. setchelli, P. meandrina; and Porites lutea. Growth forms in the surge channels are mostly encrusting, low flattened massive growths, or cespitose with closely set branches (Fig. 56). In open pools the growth forms are more like the forms encountered on the shoreward half of the submarine terrace. Corals encountered in cavernous regions of surge channels and pools were mostly encrusting forms of Psammocora nierstraszi, Chyphastrea chalcidicum Porites sp. 1, and an encrusting growth form of Coscinaraea columna. Cespitose growth forms are predominant when considering the entire reef margin zone (Table 13).

Corals not encountered on the reef margin quadrat stations, but commonly observed there were: Acropora abrotanoides, A. smithi, A. surculosa; Hydnophora microconos; Pavona clavus, P. (Pseudocolumnastraea) pollicata; and Stylocoeniella armata. Porites sp. 1 and Stylocoeniella armata were found in all three reef margin habitats in small holes, cracks, and on

Table 13. DISTRIBUTION OF CORAL GROWTH FORMS BY REEF ZONES AT TANGUISSON POINT, 1970. Relative frequency of occurrence is expressed as a percentage of the total number of colonies found in a transect zone. Data from Transects A, B, and C are combined.

	Outer Reef Flat		Reef Margin		Reef Front		Submarine Terrace		Seaward Slope		All Zones Combined	
Growth Form	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.
Massive	0		19	10	128	20	41	13	14	9	202	16
Encrusting	1	12	31	17	376	59	250	78	130	81	788	61
Foliaceous	0		0		0		0		5	3	5	1
Flabellate	0		5	3	7	1	1	1	0		13	1
Corymbose	0		13	7	29	5	0		0		42	3
Cespitose	7	88	112	62	80	13	25	8	8	5	232	18
Arborescent	0		1	1	8	1	0		0		9	1
Phaceloid	0		0		4	1	1	1	2	1	7	1
Columnar	0		0		0		1	1	1	1	2	1
Solitary	0		0		0		1	1	1	1	2	1
TOTALS	8		181		632		320		161		1302	

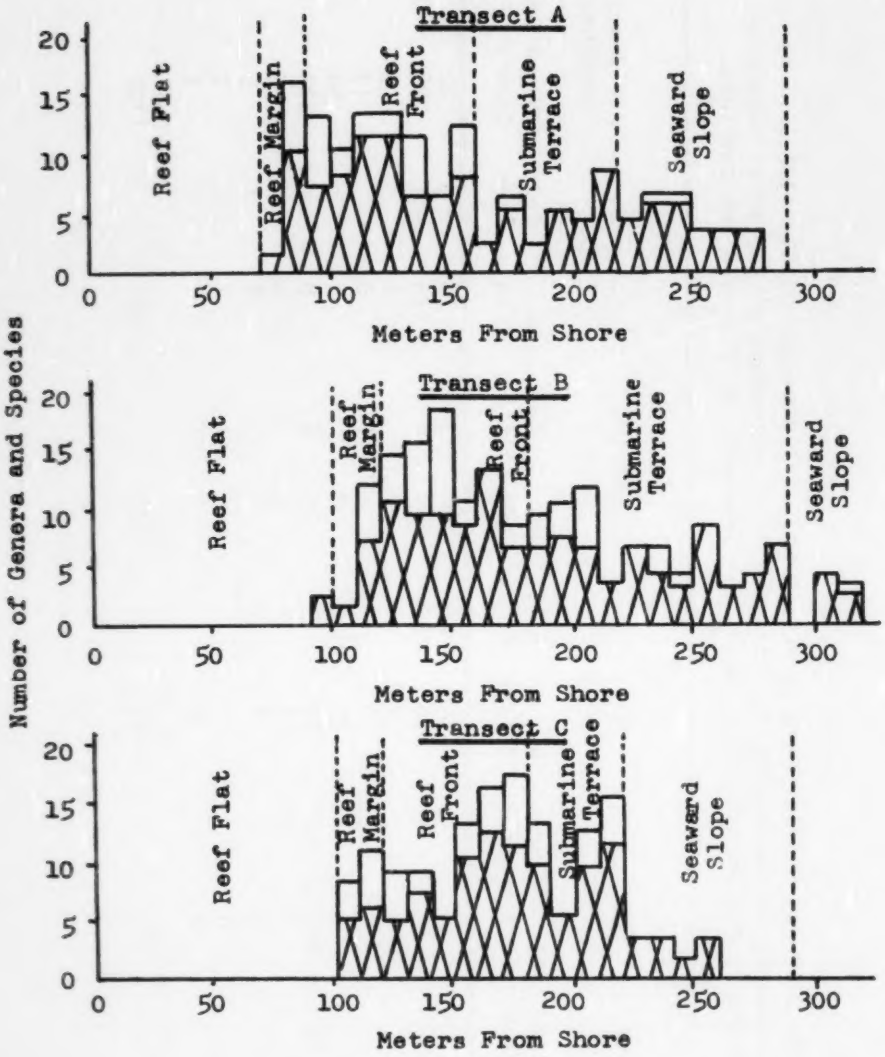

Figure 53 Number of genera and species per transect station at Tanguisson Point, 1970

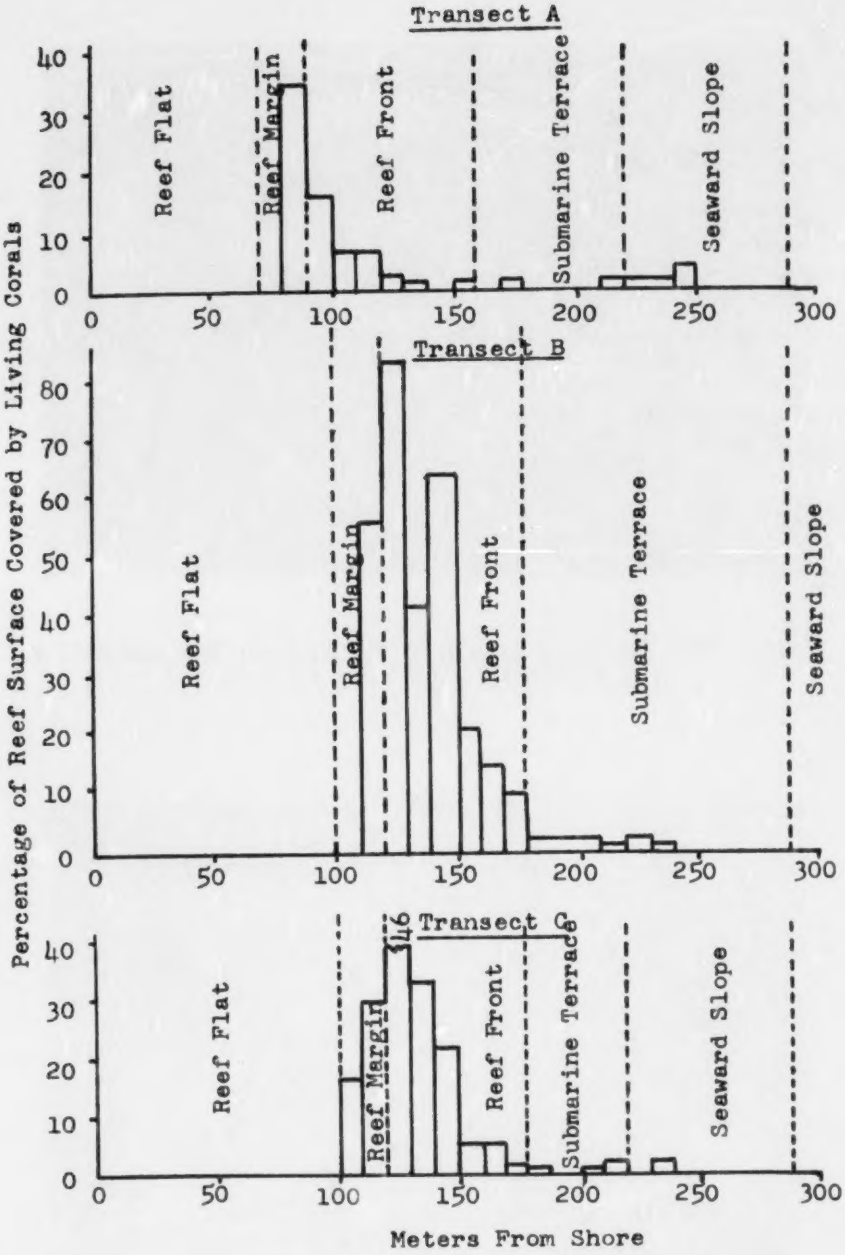

Figure 54 Percentage of reef surface covered by living corals at Tanguisson Point, 1970

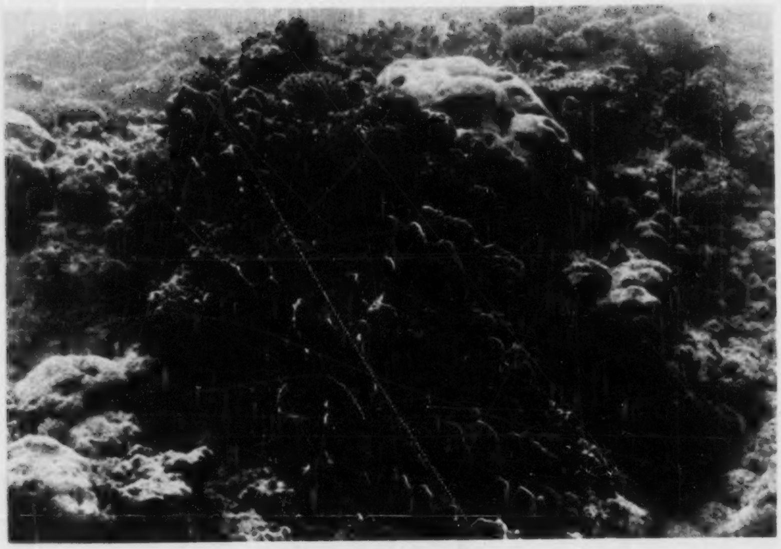

Figure 55 Rich coral growth on the upper surface and side of a reef front buttress

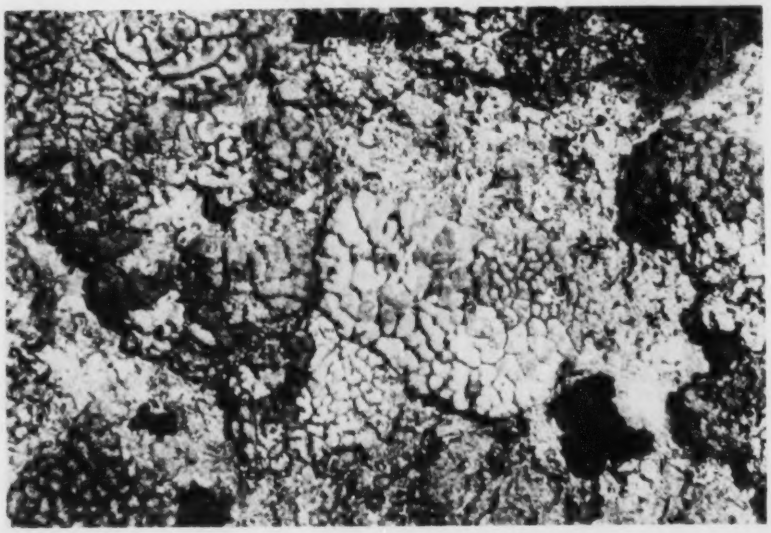

Figure 56 Dense growth of Pocillopora colonies on the floor of a reef margin surge channel

the underside of large spreading coralla.

Eighty-seven percent of the colonies measured in this zone were less than 15 cm in diameter (Table 14). The great number of small coral colonies could have been the result of coral recovery following a limited amount of *Acanthaster* predation in this zone during the summer of 1968. Surf conditions are much reduced during Summer months, thus, allowing the starfish to successfully feed in this zone. Observations of corals in the 0-5 cm range reveal that some were newly settled juvenile colonies, whereas many others were small surviving patches of larger colonies.

Reef Front Zone (50 to 70 m wide)-- Major differences in coral distribution began to emerge at the reef front zone because of prior *A. planci* activity. The percentage of reef surface covered by living corals was high only for the first one to three quadrat stations immediately seaward of the reef margin zone (Fig. 54). This high percentage of cover at first indicates that starfish predation was absent or at least nearly so along this narrow one to three quadrat band and quite high for the remainder of the zone (Fig. 54). Observations and collections at Tanguisson Point reveal that ramose, cespitose, and corymbose growth forms were previously more abundant. This was indicated by the many dead coralla of these growth forms which had been overgrown by coralline algae and various encrusting *Millepora* and *Montipora* species. Breaking waves and accompanying surge seemed to result in selective feeding by *A. planci* on corymbose and cespitose *Acropora* growth forms in this section of the reef front. During the earlier *A. planci* infestation and predation period some starfish were observed feeding in this part of the front zone. Chesher[15] also reported some starfish activity in this zone, but noted that they had difficulty in attaching their tube feet to smooth, rounded coralla. From the above data and observations, it would seem that selective feeding behavior by *A. planci* has changed the distribution of corals in this narrow band of surge and wave-assaulted reef front, but, because of coral resettlement by different species and growth forms, the percentage of corals covering the surface remained nearly the same.

Common corals observed in inner part of the reef front zone were: *Acanthastrea echinata*, *Acropora abrotanoides*, *A. studeri*, *A. hystrix*, *A. murrayensis*, *A. nasuta*, *A. surculosa*; *Favia stelligera*; *Galaxea hexagonalis*; *Goniastrea retiformis*; *Leptoria gracilis*; *Millepora platyphylla*; *Montipora verril* *Montipora* sp. 1, *Montipora* sp. 2; *Pavona varians*; *Platygyra sinensis*; *Pocillopora verrucosa*; *Porites lutea*; and *Stylophora mordax*.

Seaward of the narrow wave and surge agitated section of the reef front, the percentage of living corals covering the reef surface (Fig. 54) dropped rapidly to less than one percent for some quadrats near the submarine terrace. The reef front zone at Transect B is shallower than that

Table 14. DISTRIBUTION OF CORAL COLONY DIAMETER BY REEF ZONES AT TANGUISSON POINT, 1970. Relative frequency of occurrence is expressed as a percentage of the total number of colonies found in a transect zone. Data from Transects A, B, and C are combined.

	Outer reef flat		Reef margin		Reef front		Submarine terrace		Seaward slope		All zones combined	
Diameter Range in cm	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.	No. of Corals	Rel. Freq.
0 - 5	5	63	72	40	314	50	275	86	135	84	801	62
6 - 10	2	25	53	29	200	32	43	13	25	15	323	25
11 - 15	1	12	33	18	59	9	2	1	0		95	7
16 - 20	0		9	5	18	3	0		1	1	28	2
21 - 25	0		5	3	13	2	0		0		18	1
26 - 30	0		4	2	11	2	0		0		15	1
31 - 35	0			0	2	1	0		0		2	1
36 - 40	0			0	6	1	0		0		6	1
41 - 45	0		2	1	5	1	0		0		7	1
46 - up	0		3	2	4	1	0		0		7	1
TOTAL	8		181		632		320		161		1302	

at Transects A and C. This extends the wave-assaulted section of Transect B farther, thus lessening the degree of starfish infestation seaward and explains the presence of a fairly high percentage of living coral found covering the reef surface over the outer part of the zone (Fig. 54). Observations of dead coralla (Fig. 51) indicated that species composition, colony diameter, and growth forms were very similar to those found living at Tumon Bay (Randall[12]). Even though slightly less relief of topophic growth structures such as coral-algal knobs, bosses, and pinnacles, was noted at Tanguisson Point, it is still obvious that reef development was taking place like that at Tumon Bay.

Most living colonies encountered were either small, regenerated parts of larger, older, dead coralla, or small encrusting coralla from new planula settlement. Prior *A. planci* predation did not, in many cases, kill the entire corallum. Some small, inacessible sections of the corallum, especially if of irreguler lobate or cuneate growth form, survived the predation. These surviving sections resume growth by growing upward and spreading outward over dead parts of the parent corallum and appear as small encrusting patches. Most young colonies established from newly settled planulae also appear as small encrustations, even though later growth development may be of ramose or massive form. Corallum diameter was therefore, small (Table 14) and the number of encrusting growth forms was high (Table 13) because of patchy regeneration and the presence of newly settled corals. Some corals observed to be regenerating from surviving parts of older colonies were: *Cyphastrea serailia*; *Favia stelligera*; *Goniastrea parvistella*, *G. retiformis*; *Leptoria gracilis*; *Lobophyllia corymbosa*, *L. costata*; *Pavona clavus*; *Plesiastrea versipora*; *Porites australiensis* and *P. lutea*. Corals that were developing from newly settled planulae were: *Acropora studeri*, *A. humilis*, *A. surculosa*, *Astreopora* sp. 1; *Favia favus*, *F. pallida*; *Favites complanata*; *Leptastrea purpurea*, *Leptastrea* sp. 1; *Millepora platyphylla*; *Montipora foveolata*, *M. granulosa*, *M. verrilli*, *Montipora* sp. 1, *Montipora* sp. 3, *M. conicula*; *Pavona varians*; *Pocillopora* sp. 1 and *Porites lutea*.

Table 12 lists 65 species representing 24 genera for the reef front zone. Adding to this list those species collected but not observed at the transect stations (Table 11), increased the total species for the zone to 69 species representing 24 genera.

Submarine Terrace Zone (40 to 110 m wide) and Seaward Slope Zone (50 to 70 m wide) -- The submarine terrace and seaward slope zones were the most heavily infested with *A. planci* during the initial invasion, and as a result nearly all the original coral populations were killed (Figs. 51 and 57). Regeneration of small sections of larger colonies and resettlement of some corals had taken place as described for the reef front, but to a lesser degree, especially on the seaward slope.

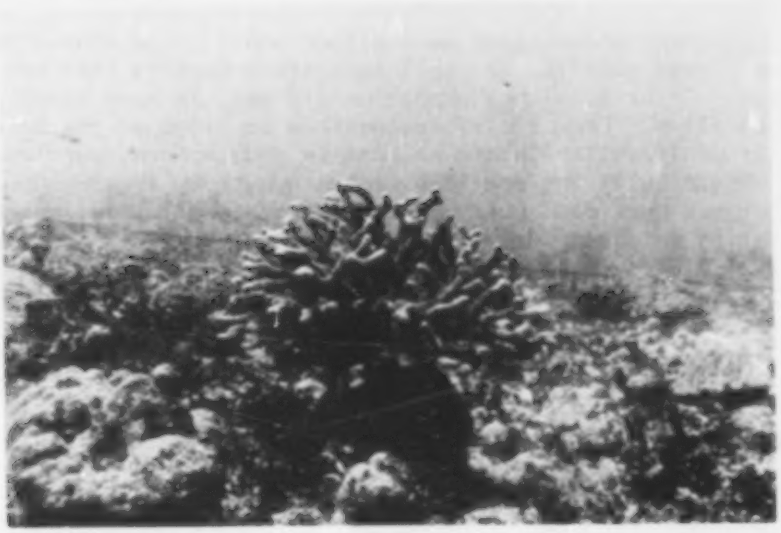

Figure 57 A view looking down the steep seaward slope zone

Eighty-six to 84 percent of the corals were less than 5 cm in diameter (Table 14) and 78 to 81 percent were of encrusting growth form (Table 13). The average percentage of living coral covering the reef surface in these zones (Fig. 54) was less than one. At Transect A, station 25, the highest percentage of coral coverage (4%) was found, caused by a single patchy, living colony of Porites (Synarea) horizontalata. Figure 53 shows a drop in the number of genera and species per transect station from that found in the reef front zones.

For the submarine terrace zone, 45 species represented by 22 genera (Table 12) occurred within the quadrat stations. Specimen collections made in this zone increased the number of species and genera to 47 and 24 respectively. The most common corals encountered on the submarine terrace were: Favia favus, F. pallida, F. stelligera; Goniastrea parvistella, G. pectinata; Leptastrea purpurea; Leptoria phrygia; Millepora exaesa; Montipora verrilli, Montipora sp. 1, Montipora sp. 3; Pavona varians; Porites lobata and P. lutea.

The total number of species occurring on the seaward slope transects was 28 species representing 19 genera (Table 12). If the corals observed off the transects in this zone are added to the above, the number is raised to 32 species and 21 genera. This was a considerable reduction when compared to the submarine terrace and was related to less regeneration from older colonies and a reduction in the number of new corals developing from planulae settlement. A considerable number of dead coralla of some species was encountered on the seaward slope that were not observed as living species (Table 11). This indicated that not all the original species were regenerating in this zone, nor had resettlement of these species taken place. Some of the dead coralla that could be identified in the field and that were not observed as living on the seaward slope transect stations were: Acropora rayneri, A. rambleri, A. palifera; Coscinaraea columna; Cyphastrea serailia; Goniopora sp.; Hydnophora microconos; Pachyseris speciosa; Psammocora exesa, P. (Stephanaria) togianensis; Plesiastrea versipora, plus some tuberculate Montipora species. Common living corals observed on the seaward slope were: Favia pallida; Galaxea fascicularis; Leptastrea purpurea, L. transversa, Leptastrea sp. 1; Montipora sp. 1; Porites lutea; and Stylocoeniella armata.

Observations of the submarine terrace and seaward slope zones at Tanguisson Point and from other reefs of Guam indicate that some coral species are not usually preyed upon by A. planci (Fig. 57). Some of these corals observed at Tanguisson Point were: Acanthastrea echniata; Diploastrea heliopora; Galaxea fascicularis, G. hexagonalis; Goniopora columna; Heliopora coerulea; Millepora dichtoma, M. exeasa, M. platyphylla; and and Pocillopora eydouxi.

Comparison of Coral Reefs at Tumon Bay and Tanguisson Point

Comparisons of physical reef characteristics and coral distribution indicate that the reef margin, reef front, submarine terrace, and seaward slope zones at Tumon Bay and Tanguisson Point were similar (except for slightly less topographic relief at the latter) in reef development before starfish predation took place (Randall[12]). The only zones not comparable at the two locations are the subzones of the reef flat, which were not initially infested with starfish during the population explosion stage. Based on the above assumptions, a comparison can be made of the coral communities between the two study locations.

The following data summarize the number of genera and species, for the major divisions of corals, at Tumon Bay before the Acanthaster infestation and Tanguisson Point after the infestation.

	Tumon Bay (From Randall[12, 18])		Tanguisson Point	
	Genera	Species	Genera	Species
Hermatypic Scleractinians	31	139	30	91
Ahermatypic Scleractinians	2	2	0	0
Non-Scleractinians	3	5	3	5
Total	36	146	33	96

The data above show that the total number of living coral genera surviving the A. planci predation is nearly the same as that found before predation. The only genera not found at Tanguisson Point, after the starfish predation, but that were earlier found at Tumon Bay before the starfish predation were Euphyllia, Paracyathus, and Polycyathus. Of these three genera, two (Euphyllia and Polycyathus) were more or less restricted to the reef flat and Paracyathus is an ahermatypic coral of little importance in terms of reef building. The high number of genera surving A. planci predation, even though of low density, may be essential in the recovery of devastated reefs if diversity of seed populations is an important prerequisite.

The number of species found on the Tanguisson reefs after A. planci predation is 34 percent less than at Tumon Bay. The number is reduced to 27 percent if those species that are specific for the reef flat moat, which is well developed only at Tumon Bay, are discounted.

Comparisons of Coral Distribution by Reef Zones -- The number of coral genera and species that were observed or collected from the various reef zones at Tumon Bay and Tanguisson Point are shown in Table 15.

Table 15. TOTAL NUMBER OF GENERA AND SPECIES BY REEF ZONES.

	Tumon Bay (From Randall[12]), before *Acanthaster*		Tanguisson Point after *Acanthaster*	
Reef Zone	Genera	Species	Genera	Species
Reef margin	14	26	12	21
Reef front	32	98	24	69
Submarine terrace	28	73	24	47
Seaward slope	26	57	21	32

Some *A. planci* predation occurred in the reef margin zone at Tanguisson, but not to the extent that coral distribution was greatly changed there. *A. planci* predation has caused extensive damage in the reef front zone. A 30 percent reduction in the number of species and a 25 percent reduction in the number of genera has occurred in this zone. Coral damage to the reef front zone is not uniformly distributed across it. A comparison of Figure 54 with Table 16 shows that the inner (shoreward) sections of the reef front zones at Tanguisson Point have a near pre-starfish percentage of reef surface covered by living corals, while the outer (seaward) sections show a great reduction.

Table 16. AVERAGE PERCENT OF CORAL COVER BY REEF ZONES.

	Tumon Bay Transects (From Randall[12]), before *Acanthaster*	Tanguisson Point Transects, after *Acanthaster*
Reef margin	26.4	22.6
Reef front	49.1	20.9
Submarine terrace	59.1	0.9
Seaward slope	50.1	0.5

However, a comparison of Figure 53 with Table 15 shows that the inner (shoreward) part of the reef front has changed in the number of coral species even though the percentage of living coral coverage (Fig. 54) has not greatly changed. Upon close inspection of this zone, it was found that A. planci predation had selectively killed many of the ramose growth forms of corals, especially the acroporoid species. This selective predation resulted in lowering the percentage of reef surface coverage, but subsequent resettlement and regeneration of encrusting coral growth forms has restored the normal percentage of coral cover found there. This section of the reef front is located in a zone of wave agitation where starfish have difficulty in remaining attached to coralla other than ramose forms and, as a result, selective predation occurs. Future assessment of coral damage caused by A. planci on the wave-assaulted regions of the reef front zones, and possibly the reef margin as well, must therefore be made with care. It is within this section of the reef front where near optimum coral reef development takes place and probably optimum coral growth rates as well. Many regions in Guam and other parts of the Indo-Pacific possess reefs that have undergone A. planci predation in the past several years. Resettlement and regeneration of specific fast growing corals may, by now, have obscured much of the coral damage in the wave assaulted reef zones.

Quantitative transect data for the submarine terrace and seaward slope zones at Tumon Bay were not recorded before A. planci predation there, but species diversity and percent of coral coverage studies of these zones were made (Randall[12]). The number of of major coral species and genera observed in these zones at Tanguisson Point indicate a similar degree of development to that which was previously found at Tumon Bay (Randall[12]). The number of species found on the submarine terrace and seaward slope at Tanguisson Point is much lower than at Tumon Bay because of the extensive starfish damage. Table 16 shows that the total reef surface occupied by living corals on the submarine terrace and seaward slope averages less than one percent of surface coverage at Tanguisson, whereas at Tumon Bay the mean percent of coverage for six sample quadrats at each zone was 59.5 and 50.1 respectively. It was in these two zones that A. planci predation was most intense. It was astonishing to see such large areas of previously living coral killed in less than a year's time by A. planci.

Comparison of Corallum Size Distribution -- There has been a shift in corallum size in all reef zones where corals were killed by Acanthaster. This shift was less intensive on the reef margin and inner part of the reef front zones. At Tanguisson Point 99 percent of the coralla found in zones of previous starfish predation were less than 10 cm in diameter, whereas at Tumon Bay less than 50 percent were in this size range for the same zones. Reduction in corallum size in regions of starfish predation is due to the small size of newly established coralla and the small size of regenerating parts of older, larger coralla that survived the initial A. planci predation.

CORAL RECOVERY (1970 to 1974)

The purpose of this part of the study is to assess, over a period of four-and-a-half years, the changes that have occurred in the distribution of reef corals in the Tanguisson area. The first distributional analysis of the reef corals was made during the first six months of 1970 and discussed above. A second analysis was made during the same period in 1971 (Randall[14]) and a third was made in October, 1974. Living corals were found at 59 stations in 1970, at 65 stations in 1971, and at 62 stations in 1974. In regard to stations with living corals present from 1970 to 1971, there was a gain and a loss of one station each on the outer reef flat zone, a loss of one station on the reef margin zone, and a gain of seven stations on the seaward slope zone. From 1971 to 1974, there was a loss of three stations at Transect B where the corals were killed by the thermal plume from the Tanguisson Power Plant.

The number of living coral colonies found within the confines of the quadrat stations was 1302 in 1970, 2116 in 1971, and 2816 in 1974. The following data summarize the changes in the number of colonies found in the quadrat stations from 1970 to 1974 by reef zones.

Zone	1970	1971	1974
Reef Flat	8	8	6
Reef Margin	181	166	40
Reef Front	632	789	918
Submarine Terrace	320	632	1035
Seaward Slope	161	521	817
TOTALS	1302	2116	2816

The above data show that the greatest rate of new colony recruitment was during the one year period from 1970 to 1971, when there was a 62.5% increase compared to a 33.1% increase for the three-and-one-half year period from 1971 to 1974. Highest coral recruitment is found in those zones which previously sustained the greatest degree of coral damage from *Acanthaster planci* predation. Although the reef front zone shows relatively less coral recruitment, than the submarine terrace or seaward slope zones, the inner part of this zone was not greatly damaged by *A. planci* infestation, which tends to mask the rather vigorous recruitment which is actually taking place in the outer part of the zone where damage to corals was much greater. There has been a steady decline in the number of colonies in the reef margin zone because of the corals that have been killed there by hot water effluent from the Tanguisson Power Plant at Transect B and to some extent at Transect C.

Species Comparison

Table 17 lists the coral species composition along with their relative frequency of occurrence on the fringing reef at Tanguisson Point during the 1970, 1971 and 1974 study periods and for the Tumon Bay control reef studied in 1968. At the control reef, 15 species are more or less restricted to the reef flat zones (Table 17). These restricted species would not be expected to occur at Tanguisson Point because the reef flat zones are poorly developed there and a well defined inner reef flat "moat" is absent.

Table 17 shows, that from a total of 96 species and 33 genera found at Tanguisson Point during the 1970 study, all but eight species and one genus were again found during the 1971 study and by 1974 all but two of the species were again found. Twenty-two species and six genera were found in the 1971 study which were new to the Tanguisson Point area and 42 new species and six new genera were found in 1974. Of the 22 new species records found in 1971, 12 were new to the Tumon Bay control reef and of the 42 new species found in 1974, 13 were also new to the control reef area. At Tanguisson Point from 1970 to 1971, the relative frequency of occurrence for 88 common species increased for 41, decreased for 44, and remained unchanged for three species. From 1970 to 1974, 94 common species showed frequency of occurrence increased for 30, decreased for 60 and was unchanged for five. This decreasing frequency of occurrence trend indicates a reduction in the new colony recruitment rate which may be related to the greater percentage of reef substrate surface which is now colonized by living corals (Table 20).

For the reef as a whole, Table 18 shows that the total number of genera has increased by five at Tanguisson Point from 1970 to 1971 and by six from 1970 to 1974. This increases the total number of genera found at Tanguisson Point in 1974 to 39, which is greater than the total of 36 found at the Tumon Bay control reef prior to the *A. planci* infestation period. The same table, shows an increase of 14 species from 1970 to 1971 and 40 species from 1970 to 1974, but unlike the number of genera which now surpasses that found at the Tumon Bay control reef, the number of species is still considerably below that found prior to the starfish infestation period.

A zonal analysis (Table 19) shows very little change in the number of genera and species on the inner reef flat, reef margin, and reef front zones. Only small changes should be expected in these zones since there has been comparatively little *Acanthaster* damage to the corals on this part of the reef. Greatest changes have occurred in the submarine terrace and seaward slope zones where *Acanthaster* predation on corals was more intense, although there has been a slight reduction in the number of genera and species in the reef front zone quadrat stations because of

Table 17. CHECKLIST OF CORALS AND THEIR RELATIVE FREQUENCY OF OCCURRENCE. Relative frequency for each species is expressed as a percentage of the total number of colonies found on a transect. [# indicates that the species was not found on the transects proper, but was observed in the study area. ( ) indicates a species more or less restricted to the reef flat at Tumon Bay.]

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Stylocoeniella armata (Ehrenberg), 1835	.36	1.69	.95	.60
Psammocora contigua (Esper), 1797	(5.03)			
Psammocora exesa Dana, 1846	.03	.15		
Psammocora nierstraszi van der Horst, 1921	.33	1.23	.71	.46
Psammocora profundacella Gardiner, 1898	.33			
Psammocora stellata (Verill), 1866	(#)			
Psammocora verrilli Vaughan, 1907	#			
Psammocora (S.) togianensis Umbgrove, 1940	.18			#
Psammocora (P.) haimeana Milne Edwards & Haime, 1851	.03	.38	.28	.25
Psammocora sp. 1			.10	
Stylophora mordax (Dana), 1846	.64	1.00	.43	.43
Seriatopora hystrix (Dana), 1846	.18		.05	#
Pocillopora brevicornis Lamarck, 1816	.30			
Pocillopora damicornis (Linnaeus), 1758	(5.84)			
Pocillopora danae Verrill, 1864	.12			.11
Pocillopora elegans Dana, 1846	#			.99
Pocillopora eydouxi Milne Edwards & Haime, 1860	.64	.15	.24	.25
Pocillipora ligulata Dana, 1846	#	#	.05	#
Pocillipora meandrina Dana, 1846	.79	2.61	2.98	1.42
Pocillipora setchelli Hoffmeister, 1929	1.12	1.77	.71	3.20
Pocillipora verrucosa (Ellis & Solander), 1786	4.03	3.23	2.36	.25
Pocillopora sp. 1		.38	.38	.11
Acropora abrotanoides (Lamarck), 1816	.42	.54	.19	.25
Acropora acuminata Verrill, 1864	(5.42)			
Acropora arbuscula (Dana), 1846	(#)			

Table 17. (continued)

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Acropora aspera (Dana), 1846	(10.69)			
Acropora brueggemanni (Brook), 1893	.18			
Acropora convexa (Dana), 1846	#			.14
Acropora cuneata (Dana), 1846	.03			
Acropora delicatula (Brook), 1891				.11
Acropora diversa (Brook), 1891	#			.04
Acropora humilis (Dana), 1846	.55	.61	.43	.82
Acropora hystrix (Dana), 1846	.18	1.31	.28	#
Acropora kenti (Brook), 1892	#	#	.14	.14
Acropora monticulosa (Bruggemann), 1879	#			.04
Acropora murrayensis Vaughan, 1918	.24	.92	.10	#
Acropora nana (Studer), 1879	2.67	2.84	3.31	1.38
Acropora nasuta (Dana), 1846	12.69	1.23	1.75	.82
Acropora nobilis (Dana), 1846	#			
Acropora ocellata (Klunzinger), 1879	.61	#	.05	1.10
Acropora palifera (Lamarck), 1816	#			#
Acropora palmerae Wells, 1954	.36	.38	.47	.36
Acropora rambleri (Bassett Smith), 1890	#		.10	.57
Acropora rayneri (Brook), 1892	#			.28
Acropora smithi (Brook), 1893	.55	.23	.24	#
Acropora squarrosa (Ehrenberg), 1834	#	#		#
Acropora studeri (Brook), 1893	1.18	.84	.33	#
Acropora surculosa (Dana), 1846	2.06	.69	.80	.60
Acropora syringodes (Brook), 1892	.30	#	.47	#
Acropora valida (Dana), 1846	.39	.15	.14	.04
Acropora wardii Verrill, 1901			.10	.28
Acropora sp. 1	.79	.07	.57	.04
Acropora sp. 2	.03			
Acropora sp. 3	#			
Astreopora gracilis Bernard, 1896	.27	.31	.24	.11
Astreopora listeri Bernard, 1896	#			.04
Astreopora myriophthalma (Lamarck), 1816	.15	.23	.80	1.49
Astreopora sp. 1	#			

Table 17. (continued)

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Montipora acanthella Bernard, 1897	(#)			
Montipora composita Crossland, 1952	#			
Montipora conicula Wells, 1954	.39	.23	.76	.07
Montipora elschneri Vaughan, 1918	.30	.76	.99	1.70
Montipora floweri Wells, 1954	#			
Montipora foveolata (Dana), 1846	.39	.61	.10	.43
Montipora granulosa Bernard, 1897		.15	.05	.14
Montipora hoffmeisteri Wells, 1954	.27	.07	.28	1.28
Montipora lobulata Bernard, 1897	.09			
Montipora monasteriata (Forskaal), 1775	.27	.23	.33	.43
Montipora patula Verrill, 1869	#			.24
Montipora planiuscula Dana, 1846	(#)			
Montipora socialis Bernard, 1897				.78
Montipora spumosa (Lamarck), 1816	#			
Montipora stilosa (Ehrenberg), 1834	#			
Montipora subtilis Bernard, 1897				.46
Montipora tuberculosa (Lamarck), 1816	.24	.23		.60
Montipora verrilli Vaughan, 1907	2.51	4.99	5.39	5.26
Montipora verrucosa (Lamarck), 1816	.39		.24	.53
Montipora sp. 1	.75	1.46	2.08	.89
Montipora sp. 2	.09	.46	.24	.14
Montipora sp. 3	.03	.61	1.65	.25
Montipora sp. 4		.38	.71	.36
Montipora sp. 5		.38	.19	.32
Montipora sp. 6			.28	#
Montipora sp. 7			.05	.25
Pavona clavus (Dana), 1846	1.36	1.38	.19	.07
Pavona decussata (Dana), 1846	(.48)			
Pavona divaricata (Lamarck), 1816	(#)			
Pavona frondifera (Lamarck), 1816	(#)			
Pavona varians Verrill, 1864	.91	3.99	3.31	2.02
Pavona gardineri van der Horst, 1922	#		.10	#

Table 17. (continued)

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Pavona (P.) pollicata Wells, 1954	.21	.07	.19	.11
Pavona (P.) planulata (Dana), 1846	.15		.47	.18
Pavona (P.) obtusata (Quelch), 1884	.03			#
Pavona (P.) sp. 1	.45			.07
Pavona (P.) sp. 2	#			
Pavona (P.) sp. 3		.54	.57	#
Leptoseris hawaiiensis Vaughan, 1907	.03	.23	.05	.11
Leptoseris incrustans (Quelch), 1886	.03			.07
Leptoseris mycetoseroides Wells, 1954			.05	.04
Pachyseris speciosa (Dana), 1846	#	#	#	#
Anomastrae sp. 1			.47	.64
Coscinaraea columna (Dana), 1846	.18	.07		#
Cycloseris cyclolites (Lamarck), 1801		.23		
Cycloseris sp. 1		.15	.19	#
Fungia fungites var. stylifera Doederlein, 1902	.06			.04
Fungia scutaria Lamarck, 1801	#		.05	.11
Goniopora columna Dana, 1846	#	.23	.19	.11
Goniopora sp. 1	.21		.05	.07
Goniopora sp. 2	.09		.24	.11
Porites annae Crossland, 1952	(.09)			
Porites australiensis Vaughan, 1918	.42	.61	1.51	.11
Porites cocosensis Wells, 1950	(.36)			
Porites compressa Vaughan, 1907	(.18)			
Porites duerdeni Vaughan, 1907	(#)			
Porites fragosa Dana, 1846				.07
Porites lichen Dana, 1846	#		.76	.71
Porites lobata Dana, 1846	1.67	1.08	4.73	5.54
Porites lutea Milne Edwards & Haime, 1851	2.60	3.69	2.22	5.79
Porites murrayensis Vaughan, 1918	#			#
Porites sp. 1	2.79	2.23	.38	.39

Table 17. (continued)

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Porites sp. 2	.03	#		.04
Porites (*S.*) *convexa* Verrill, 1864	.42	#	.10	.07
Porites (*S.*) *hawaiiensis* Vaughan, 1907	#	.07	.85	1.03
Porites (*S.*) *horizontalata* Hoffmeister, 1925	#	.07		#
Porites (*S.*) *iwayamaensis* Eguchi, 1938	1.03	1.23	1.13	.64
Porites (*S.*) sp. 1	#			
Alveopora verrilliana Dana, 1872	.09	#	#	.07
Favia favus (Forskaal), 1775	#	.76	.24	.82
Favia pallida (Dana), 1846	.48	3.92	2.08	2.91
Favia speciosa (Dana), 1846	.30		2.13	2.49
Favia stelligera (Dana), 1846	2.13	5.38	3.64	3.62
Favia rotumana (Gardiner), 1889	#	.15	.14	.32
Favites abdita (Ellis & Solander), 1786	.03			.04
Favites complanata (Ehrenberg), 1834	.67	1.31	2.08	1.49
Favites favosa (Ellis & Solander), 1786		.15	.14	#
Favites flexuosa (Dana), 1846		.07		.04
Favites virens (Dana), 1846			.24	.18
Oulophyllia crispa (Lamarck), 1816			.05	.07
Plesiastrea versipora (Lamarck), 1816	.39	1.31	.80	1.21
Plesiastrea lilli Wells, 1954			.05	
Plesiastrea sp. 1	.27			
Goniastrea parvistella (Dana), 1846	.46	1.31	.99	1.28
Goniastrea pectinata (Ehrenberg), 1834		.84	1.04	.64
Goniastrea retiformis (Lamarck), 1816	3.48	6.68	7.14	3.87
Platygyra rustica (Dana), 1846	.39	.69	.10	.11
Platygyra lamellina (Ehrenberg), 1834			.05	#
Platygyra sinensis (Milne Edwards & Haime), 1849	.33	.61	1.23	1.14
Leptoria gracilis (Dana), 1846	1.36	2.53	1.23	.82
Leptoria phrygia (Ellis & Solander), 1786	.09	2.30	.80	.32
Hydnophora microconos (Lamarck), 1816	.33	.07	.14	.14
Leptastrea bottae (Milne Edwards & Haime), 1849	#			.04

Table 17. (continued)

	Tumon Bay control reef 1968	Tanguisson Point 1970	Tanguisson Point 1971	Tanguisson Point 1974
Leptastrea purpurea (Dana), 1846	2.27	2.46	4.40	10.54
Leptastrea transversa (Klunzinger), 1879		1.31	1.65	.65
Leptastrea sp. 1	.21	1.08	3.97	4.58
Cyphastrea chalcidicum (Forskaal), 1775		.46	.28	.14
Cyphastrea serailia (Forskaal), 1775	.36	.07	1.13	1.70
Cyphastrea sp. 1	.51			
Echinopora lamellosa (Esper), 1787	.09	.38	.10	#
Diploastrea heliopora (Lamarck), 1816	.09	#	.14	.04
Galaxea fascicularis (Linnaeus), 1758	.24	1.38	.14	#
Galaxea hexagonalis Milne Edwards & Haime, 1857	2.36	8.29	7.69	6.61
Merulina ampliata (Ellis & Solander), 1786			.05	.04
Lobophyllia corymbosa (Forskaal), 1775	.27	.31	.14	.07
Lobophyllia costata (Dana), 1846	.21	.46	.19	.18
Acanthastrea echinata (Dana), 1846	.48	2.53	.71	1.24
Echinophyllia asper Ellis & Solander, 1786		.23	.85	1.14
Mycedium sp. 1			.14	.04
Paracyathus sp. 1	#			
Polycyathus sp. 1	#			
Euphyllia glabrescens (Chamisso & Eysenhardt), 1821	#			#
Heliopora coerulea (Pallas), 1766	.24	.07	.10	.07
Millepora dichotoma Forskaal, 1775	.18	.07	#	.04
Millepora exaesa Forskaal, 1775	.88	1.15	1.94	1.42
Millepora platyphylla Hemprich & Ehrenberg, 1834	1.12	1.77	1.23	.67
Distochopora violacea (Pallas), 1776	.09	.38	.14	#
Total species - 175	146	96	110	136
Total number of colonies	3302	1302	2116	2816

Table 18. NUMBER OF GENERA AND SPECIES FOR THE MAJOR GROUPS OF CORALS FOUND AT TUMON BAY AND TANGUISSON POINT FROM 1970 to 1974. Values enclosed by parentheses indicate the number of coral genera and species found only on the transect stations. Values not enclosed by parentheses indicate the number found on the transect stations plus additional genera and species found by making observations of the reef surface located between Transect A and Transect C.

	Tumon Bay Control Reef (1968)		Tanguisson Point (1970)		Tanguisson Point (1971)		Tanguisson Point (1974)	
	Genera	Species	Genera	Species	Genera	Species	Genera	Species
Hermatypic Scleractinians	31 (29)	139 (98)	30 (27)	91 (81)	35 (33)	105 (103)	36 (30)	131 (107)
Ahermatypic Scleractinians	2 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Non-Scleractinians	3 (3)	5 (5)	3 (3)	5 (5)	3 (3)	5 (4)	3 (2)	5 (4)
Totals	36 (32)	146 (103)	33 (30)	96 (86)	38 (36)	110 (107)	39 (32)	136 (111)

thermal discharge at Transect B.

Figures 58-60 show the number of genera and species for each transect by stations and reflects more exactly where changes have occurred. Two artifacts are present in Figures 59 and 60. The first is at Transect A in the reef margin zone and the second at Transect B in the reef margin and inner (shoreward) part of the reef front zones. At both of these transect locations a reduction in the number of genera and species has occurred. At Transect A this reduction was caused by a bloom of a blue-green alga, *Anacystis dimidiata* which, in a small localized region, covered nearly 100 percent of the reef surface. Many corals were killed as a result of their living tissues being covered by gelatinous shards of this alga. At Transect B the reduction was caused by the presence of heated effluent from the power plant outfall. Transect B bisects a portion of the outfall plume. Nearly all the corals have been killed on the reef margin and inner (shoreward) part of the reef front zones. Figures 58, 59, and 60 otherwise show that greatest changes in the number of genera and species has taken place on transect stations located on the submarine terrace and seaward slope zones.

It appears then, that species diversity is increasing fairly rapidly at Tanguisson Point, which is due in part to the recolonization of not only the former species which commonly occurred there, but also to species that do not normally occur in the area. Possibly the corals new to the area represent a pioneer group which recolonize the reef surface recently killed by *Acanthaster* predation. Porter[26] reported a similar phenomenon on the west coast of Panama where corals were killed by *Acanthaster*. As more reef surface becomes covered with living corals, especially by those species which formerly occupied the region, interspecific competition may well become an important factor which could again restore the pre-*Acanthaster* species composition to the reef. Until competition becomes a limiting factor at Tanguisson Point, species richness could go beyond the 146 species level found previously at the Tumon Bay control reef.

Reef Surface Coverage by Living Corals

The percentage of living coral covering the reef surface (Table 20) increased on all transects and reef zones except for the reef margin on Transects A and C and the inner reef flat, reef margin, and reef front on Transect B. Reduction of reef surface coverage in these zones is due again to the *Anacystis dimidiata* bloom on Transect A and the presence of the outfall plume at Transects B and C. Figures 61-63 show the percent of coral coverage for each station on the three transects and indicates that the highest relative gains have taken place in the submarine terrace and seaward slope zones where *A. planci* damage to the

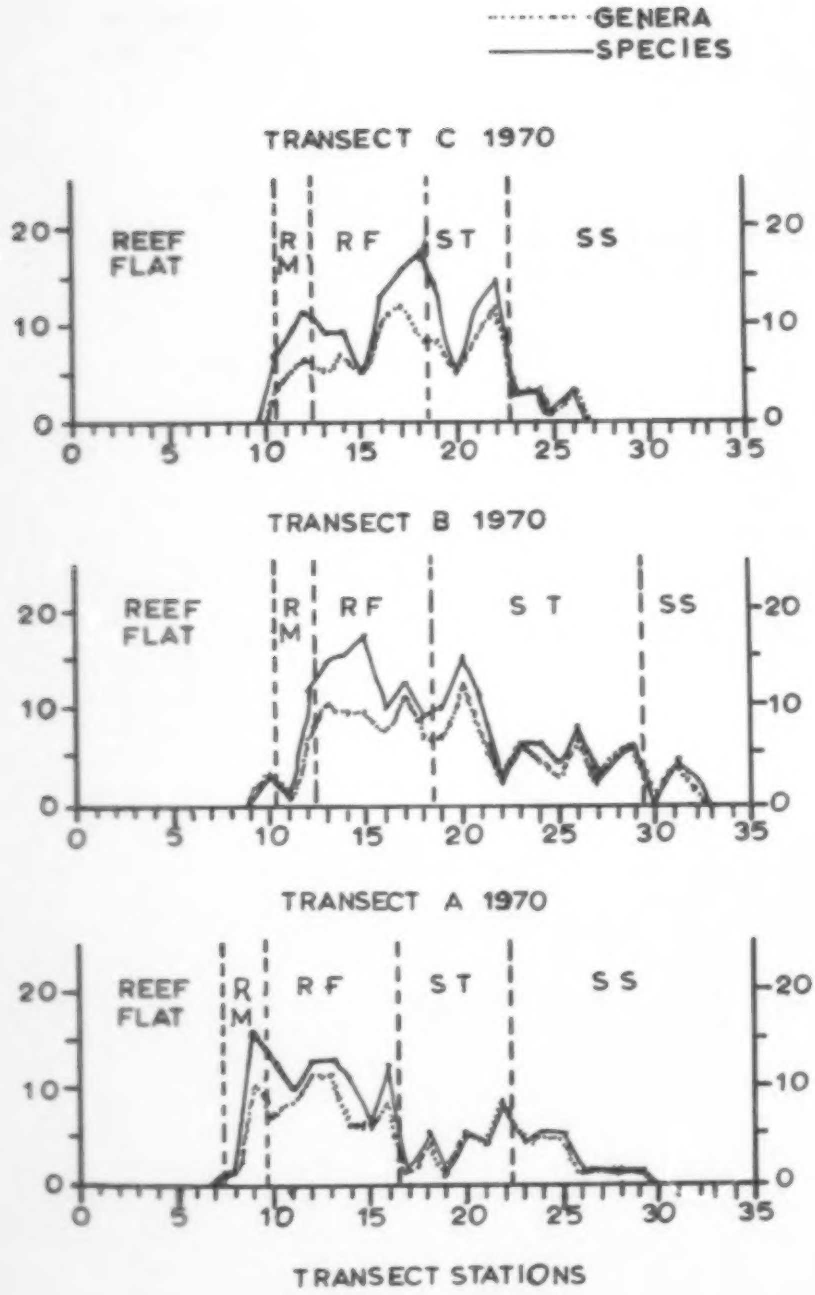

Figure 58 Number of coral genera and species per transect station for 1970

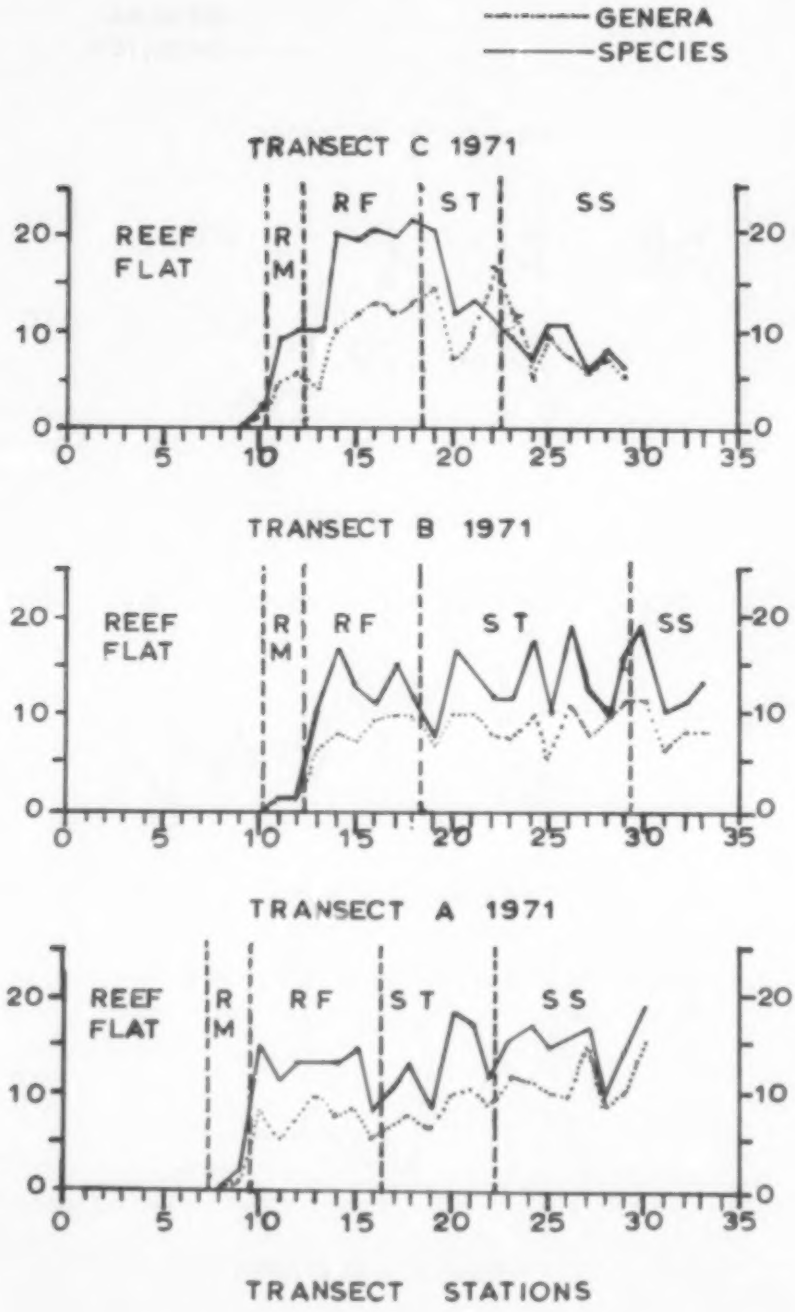

Figure 59 Number of coral genera and species per transect station for 1971

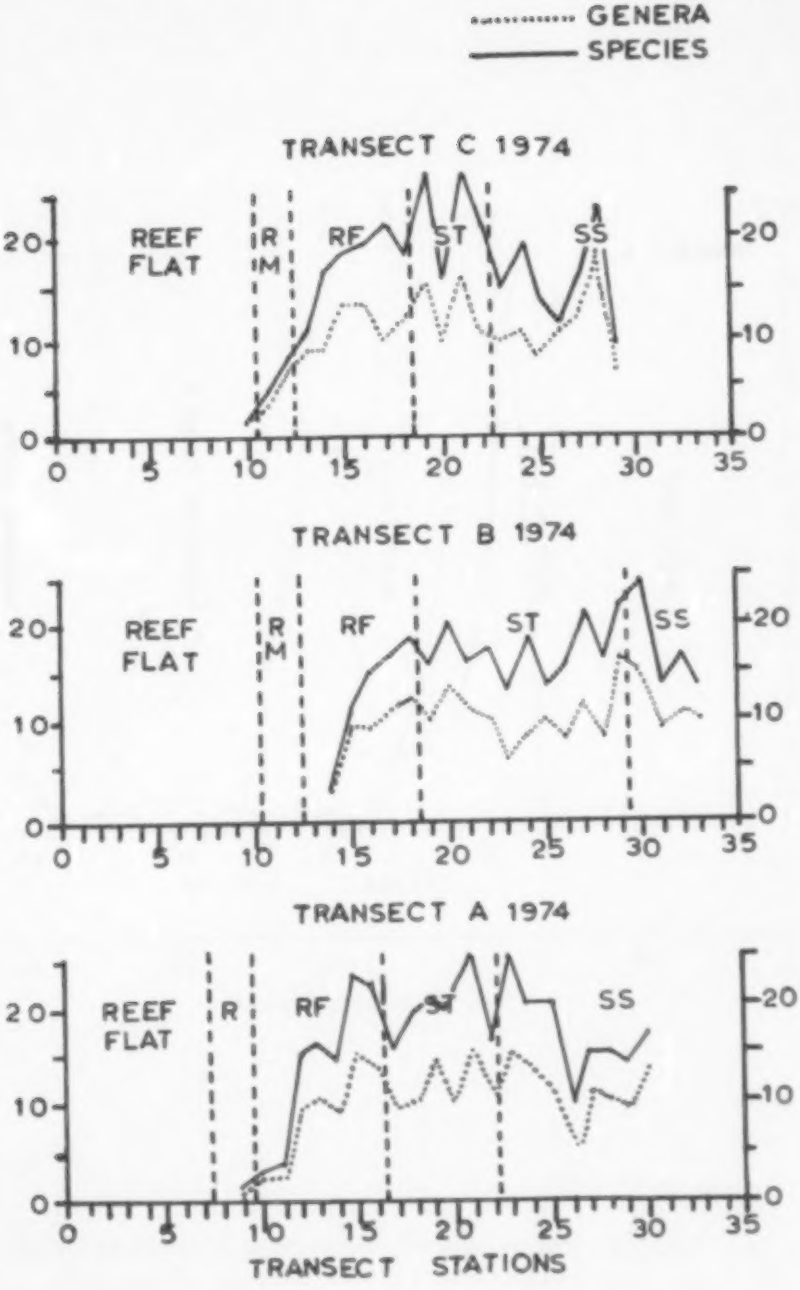

Figure 60 Number of coral genera and species per transect station for 1974

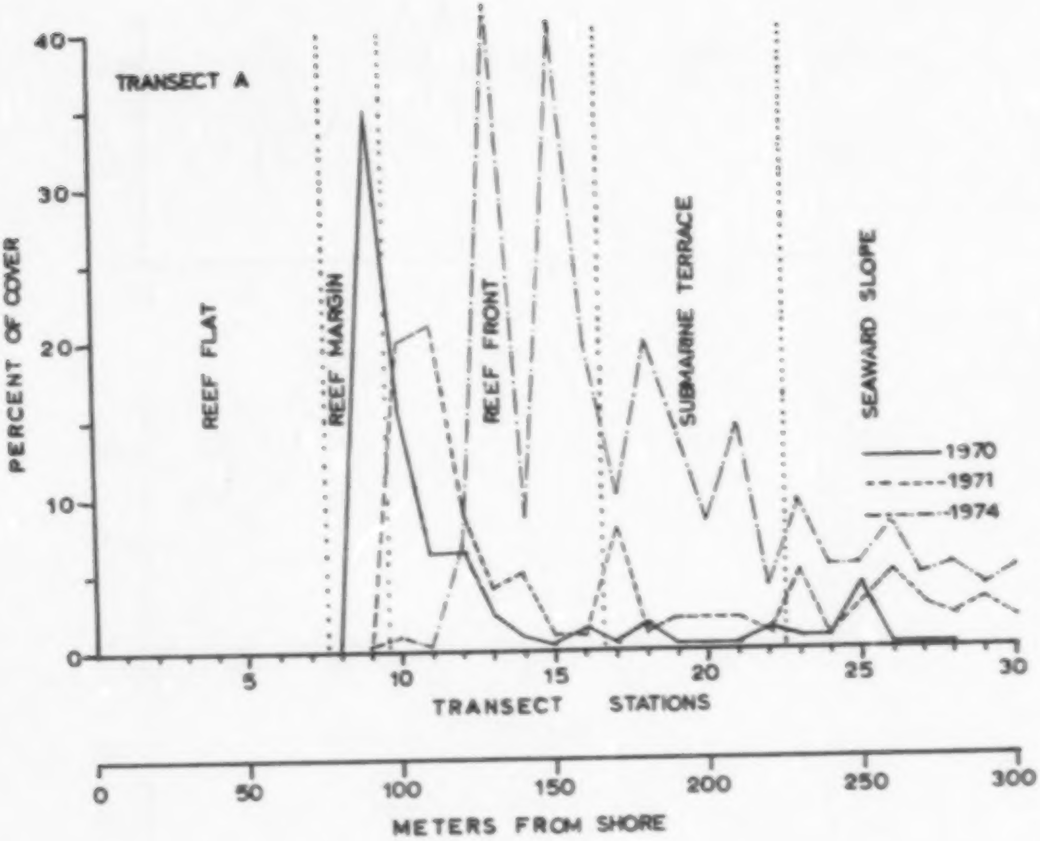

Figure 61 Percentage of reef surface covered by living corals from 1970 to 1974 for Transect A

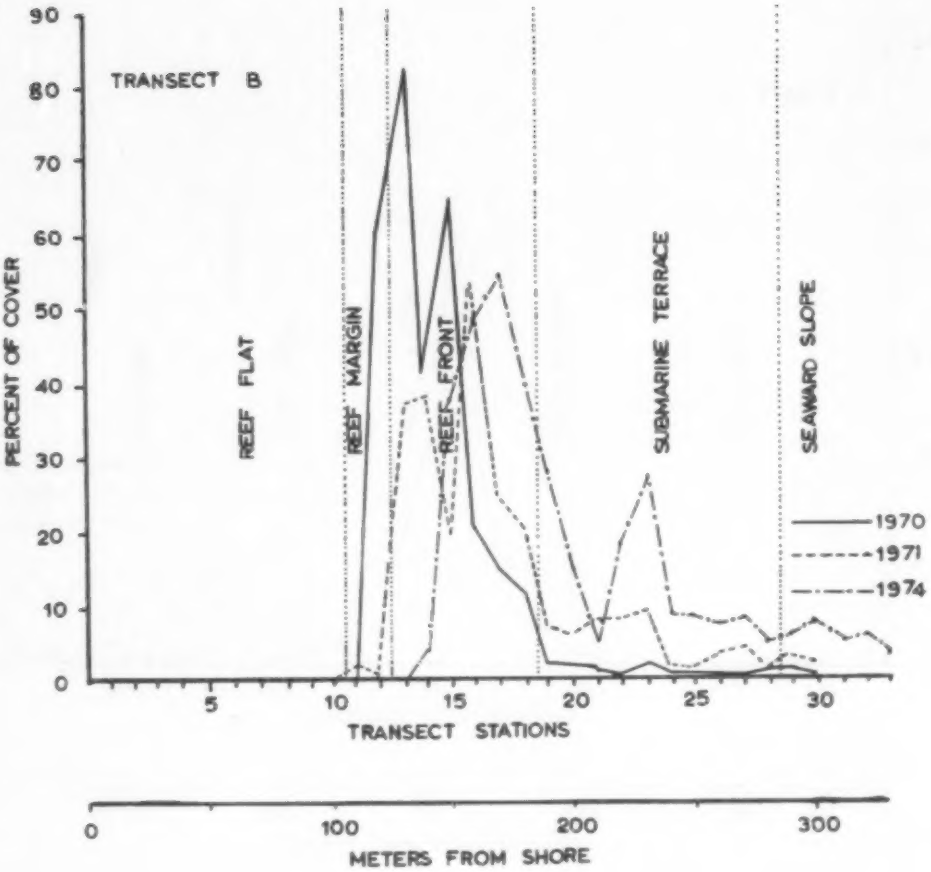

Figure 62 Percentage of reef surface covered by living corals from 1970 to 1974 for Transect B

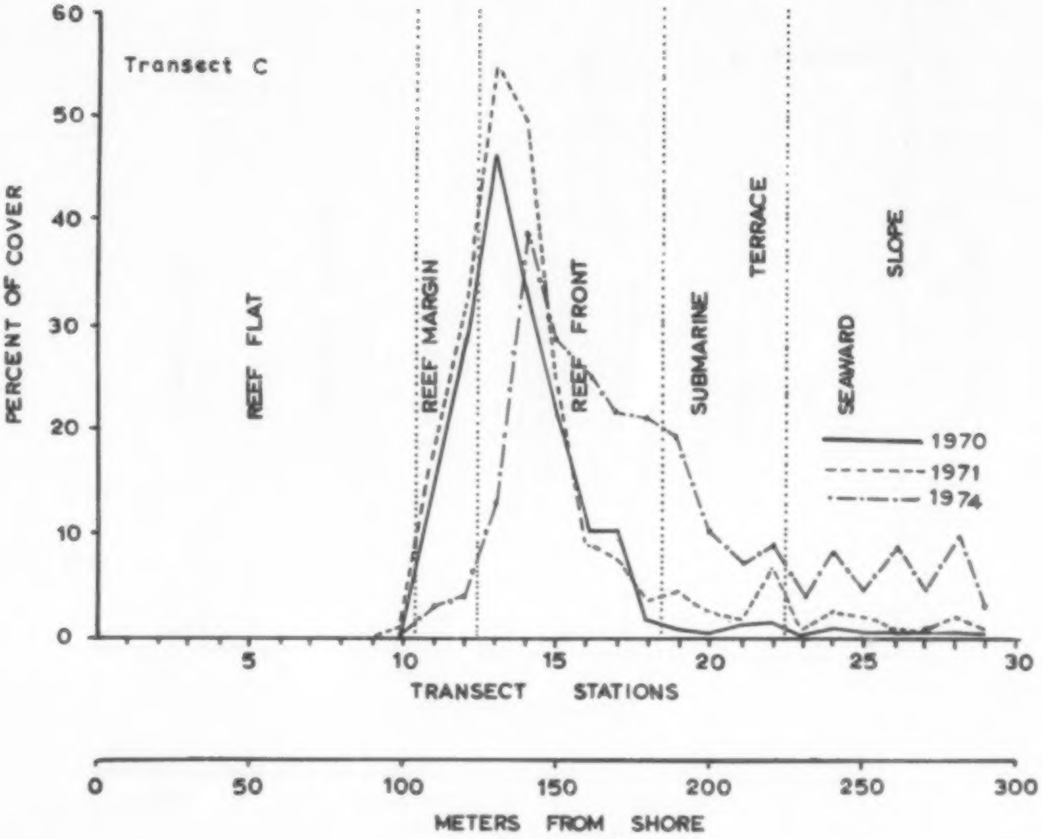

Figure 63 Percentage of reef surface covered by living corals from 1970 to 1974 for Transect C

Table 19. CHANGES IN THE NUMBER OF CORAL GENERA AND SPECIES BY REEF ZONES FROM 1970 TO 1974. Values enclosed by parentheses indicate the number of coral genera and species found only on the transect stations. Values not enclosed by parentheses indicate the number found on the transect stations plus additional genera and species found by making observations of the reef surface located between Transect A and Transect C.

Reef Zones	Tanguisson Point 1970		Tanguisson Point 1971		Tanguisson Point 1974	
	Genera	Species	Genera	Species	Genera	Species
Inner reef flat	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Outer reef flat	2 (2)	2 (2)	4 (1)	5 (2)	4 (2)	5 (2)
Reef margin	12 (12)	21 (21)	10 (10)	21 (20)	9 (8)	20 (12)
Reef front	24 (24)	70 (65)	21 (21)	68 (67)	20 (20)	71 (65)
Submarine terrace	24 (22)	47 (45)	27 (27)	70 (70)	28 (27)	93 (78)
Seaward slope	21 (19)	32 (28)	30 (30)	61 (61)	33 (28)	94 (75)

Table 20. CHANGES IN THE PERCENTAGE OF REEF SURFACE COVERED BY LIVING CORAL BY REEF ZONES FROM 1970 TO 1974. Percentages are the mean of all the quadra stations occurring within a reef zone.

Reef Zone	Transect A			Transect B			Transect C		
	1970	1971	1974	1970	1971	1974	1970	1971	1974
Outer reef flat	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Inner reef flat	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	1.0%	0.3%
Reef margin	17.5%	0.1%	0.2%	28.0%	1.5%	0.0%	22.2%	25.0%	3.9%
Reef front	5.1%	8.7%	17.0%	39.0%	32.2%	33.1%	18.8%	24.8%	24.4%
Submarine terrace	0.7%	2.7%	11.7%	1.1%	4.9%	12.8%	1.0%	4.3%	11.4%
Seaward slope	0.9%	3.0%	6.4%	0.2%	1.8%	6.1%	0.5%	1.6%	6.4%

reef corals was greatest.

Corallum Size Distribution

Table 21 lists the frequency distribution of corals by diameter for each reef zone from 1970 to 1974. The greatest number of corals are distributed in the 0-5 cm range, where 58 to 62 percent of the total number of colonies are found. These large percentages are due mainly to the new settlement and growth of coral planulae on the algal encrusted surface of corals previously killed by A. planci. Even though large numbers of corals were distributed in the 0-5 range in 1971 and 1974, sixty-two percent of the corals were also found in that range in 1970. Most of these colonies were represented, at that time,by small patches of coralla, surviving from larger colonies, that were not completely killed by A. planci. The second largest size distribution is in the 6-10 cm range which mostly represents an increase in growth of the surviving coral patches described above, plus some early recolonization from planula settlement. Most of the increase that took place in the 0-5 and 6-10 cm size ranges occurred in the submarine terrace and seaward slope zones where A. planci activity was greatest. There has been a decrease in the number of colonies in reef margin zones because of the coral kill due the algal bloom at Transect A and the outfall plume at Transect B. Most of the larger coralla are found in reef zones which were not subjected to intensive damage from A. planci.

Corallum Growth Form Distribution

If the observed increase in the total number of new colonies found at the station quadrats are due to recent coral planula settlement, then a marked increase in the number of encrusting growth forms should be expected, since most newly settled corals go through an encrusting stage early in their development. Table 22 shows such an increase in the number of encrusting growth forms, from 788 in 1970, to 1468 in 1971. An overall reduction of these forms from 1971 to 1974 probably represents the transition of some of the encrusting colonies into other growth forms, particularly those of the massive form. There has been a decrease in the number of all growth forms in the reef margin zone, and for the encrusting forms in the reef front zone from 1971 to 1974. In the reef margin zone this reduction is a result of the corals being killed by the algal bloom at Transect A from 1970 to 1971, and from the outfall plume at Transects B and C from 1971 to 1974. The reduction in the number of encrusting forms has been highest in the reef front zone which probably represents a transition of many of these into massive and cespitose growth forms.

Table 21. DISTRIBUTION OF CORALS BY DIAMETER FROM 1970 TO 1974. Data from Transects A, B, and C are combined.

Reef zones	Outer reef flat			Reef margin			Reef front			Submarine terrace			Seaward slope			All zones combined		
Dia. range in cm	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974
0 - 5	5	6	6	72	31	19	314	326	385	275	451	640	135	428	569	801	1242	1619
6 - 10	2	1	0	53	92	17	200	317	356	43	146	270	25	77	193	323	633	836
11 - 15	1	1	0	33	22	3	59	77	84	2	29	70	0	14	36	95	143	193
16 - 20	0	0	0	9	8	1	18	30	42	0	3	29	1	1	17	28	42	89
21 - 25	0	0	0	5	6	0	13	13	20	0	2	16	0	1	0	18	22	36
26 - 30	0	0	0	4	4	0	11	14	14	0	1	7	0	0	1	15	19	22
31 - 35	0	0	0	0	0	0	2	4	7	0	0	2	0	0	1	2	4	10
36 - 40	0	0	0	0	0	0	6	1	2	0	0	0	0	0	0	6	1	2
41 - 45	0	0	0	2	1	0	5	3	3	0	0	0	0	0	0	7	4	3
46 - up	0	0	0	3	2	0	4	4	5	0	0	1	0	0	0	7	6	6
Totals	8	8	6	181	166	40	632	789	918	320	632	1035	161	521	817	1302	2116	2816

Table 22. DISTRIBUTION OF CORALS BY GROWTH FORMS FROM 1970 TO 1974. Data from Transects A, B, and C are combined.

Reef zones	Outer reef flat			Reef margin			Reef front			Submarine terrace			Seaward slope			All zones combined		
Growth form	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974	1970	1971	1974
Massive	0	0	0	19	18	12	128	122	297	41	44	332	14	56	379	202	240	1020
Encrusting	1	1	0	31	26	5	376	491	242	250	533	602	130	417	319	788	1468	1168
Foliaceous	0	0	0	0	0	0	0	0	0	0	0	2	5	8	7	5	8	9
Flabellate	0	0	0	5	7	2	7	7	17	1	11	0	0	0	0	13	25	19
Corymbose	0	0	0	13	24	1	29	50	65	0	4	31	0	2	23	42	80	120
Cespitose	7	7	6	112	91	20	80	107	288	5	29	59	8	20	59	232	254	432
Arborescent	0	0	0	1	0	0	8	12	7	0	0	1	0	2	5	9	14	13
Phaceloid	0	0	0	0	0	0	4	0	2	1	6	4	2	1	1	7	7	7
Columnar	0	0	0	0	0	0	0	0	0	1	5	4	1	10	19	2	15	23
Solitary	0	0	0	0	0	0	0	0	0	1	0	0	1	5	5	2	5	5
Totals	8	8	6	181	166	40	632	789	918	320	632	1035	161	521	817	1302	2116	2816

Summary

1. During 1968 and 1969, at Tanguisson Point, over 95 percent of the living reef corals were killed by A. planci in the submarine terrace and seaward slope zones. A considerable number of corals were also killed in the outer part of the reef front zone.

2. The number of living coral colonies recorded on the Tanguisson Point transects has increased from 1302 in 1970, to 2116 in 1971, and to 2816 in 1974. Most of these new colonies have developed in the submarine terrace, seaward slope, and outer part of the reef front zones.

3. From 1970 to 1974 the total number of coral genera has increased from 30 to 32 on the Tanguisson Point transects and from 33 to 39 when additional genera observed between Transects A and C are included.

4. During the 1970 to 1974 study period, the total number of species has increased from 86 to 111 on the Tanguisson Point transects and from 96 to 136 when additional species observed between Transects A and C are included.

   From 1970 to 1974 there were 42 species and six genera of corals recorded that were new to the Tanguisson Point transects. Of these new species 13 were also new to the Tumon Bay control reef. Of all the species recorded in 1970, only two were not recorded again in 1974.

5. When increases in the number of genera and species are compared by reef zones at Tanguisson Point from 1970 to 1974, there has been little change in the zones where A. planci damage was minimal (except for damage caused by the alga bloom at Transect A and the power plant effluent at Transects B and C). The most significant increases have occurred on the submarine terrace and seaward slope zones where A. planci infestation and damage to reef corals was greatest.

6. From 1970 to 1974 the percentage of reef surface covered by living corals has increased in all reef zones at Tanguisson Point except the reef margin at Transect A (reduction caused by algal bloom) and the inner reef flat, reef margin, and reef front zones at Transects B and C (reduction caused by power plant outfall). The greatest relative increase in the percentage of reef surface covered by living corals has occurred on the submarine terrace and seaward slope zones.

7. During the 1970 to 1974 study period, increases in coral size has been greatest in the 0-5 cm range and in the 6-10 cm range. Most of these increases have occurred in the submarine terrace and seaward slope zones.

8. During the study period, greatest changes in the distribution of coral growth forms has been an increase of the encrusting types from 1970 to 1971 and an increase in the massive cespitose forms from 1971 to 1974. Most of these changes have occurred in the submarine terrace, seaward slope, and outer part of the reef front zones.

Conclusions

The increase in the total number of new coral colonies observed, the increase in species diversity, and the increase in the percentage of reef surface covered by living corals indicate that coral recovery is taking place at Tanguisson. Most of the coral recovery is taking place in those zones where *A. planci* infestation and the resulting damage was greatest. The increases observed for the percentage of reef surface covered by living corals is due to recolonization by the settlement of planula and an increase in size of the few surviving patches or colonies of coral that remained after the starfish infestation period.

Based on a pre-*Acanthaster* value of 59.1 percent living surface coverage for the submarine terrace zone at the Tumon Bay control reef and an average yearly gain of 2.76 percent coverage for the submarine terrace zone at Tanguisson Point, from 1970 to 1974, it will then take this reef zone about 21.4 years to attain the same degree of coverage found before *A. planci* predation. With 50.1 percent pre-*Acanthaster* value of living coral coverage for the seaward slope zone at the control reef and an average gain of 1.44 percent coverage for the seaward slope zone at Tanguisson Point, from 1970 to 1974, it will then take the reef zone, there, about 34.7 years to attain the same degree of coverage as was found before *A. planci* predation.

The above recovery rates were determined from four years of data and a simple linear extrapolation based on the control reef values taken in 1967 and 1968. Actually, the percentage of substrate coverage rates are quite linear for the Tanguisson reef when plotted over the four year study period. Moreover, at Tanguisson Point, the structural integrity of the reef framework and accompanying structural relief features, including the once living individual coralla, are still intact. There has been little evidence observed which indicates a physical disintegration of the above eatures. As the present reef surface is recolonized, the living corals will inherit an intact substrate which possesses nearly all the structural relief features of a thriving and developing reef. An observer, unaware of the previous destruction of the living coral reef surface, would be hard pressed to detect the recent hiatus in reef development of a few years duration which was caused by *A. planci* predation.

The above reef recovery hypothesis is, at best, tenuous and based only on gains in reef "surface coverage" by living corals. For a reef to attain a massive framework development, from a disintegrated reef surface, it might take a much longer period of time, possibly as much as the 700 years predicted by the late T. F. Goreau[27].

CORAL RECOLONIZATION IN THE INTAKE CHANNEL

An intake channel was excavated across the reef flat platform and reef margin to provide access for cooling water to plant condensers. The excavation comprises an area of about 1835 m^2 in the reef flat zone and an area of about 250 m^2 at the reef margin zone. Since the part of the channel once occupied by the intertidal reef flat platform is now permanently 1.5 to 2.5 m deep, it was expected that some coral colonization and growth would appear on the channel walls and floor.

On October 16, 1974, a survey was made to determine the degree, if any, to which corals had recolonized the new subtidal channel surfaces. The channel sides consist of steeply-sloping, rather blocky irregular limestone walls and the channel floor consists of poorly sorted limestone boulders, gravel and sand.

The inner two-thirds of the channel floor and inner third of the channel walls were devoid of corals. The outer two-thirds of the channel walls possessed widely scattered corals, none of which were greater than 15 cm in diameter. In order of their abundance, the corals observed were *Pocillopora damicornis*, *Pocillopora setchelli*, *Acropora surculosa*, *Acropora nasuta*, *Acropora abrotanoides*, *Acropora plamerae*, and *Pocillopora brevicornis*. Overall the coral density along the channel wall was less than one per square meter and the percentage of substrate covered by living coral was less than one percent.

The outer third of the channel floor has even fewer corals than the channel walls. It appears that the unstable boulders, gravel, and sand in the channel floor prevents coral development except for an occasional colony growing on a larger more stable limestone block or boulder. Corals observed in their order of abundance were *Pocillopora damicornis*, *Porites lutea*, *Acropora nasuta* and *Acropora surculosa*.

SECTION XI

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SECTION XII

APPENDICES

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APPENDIX A

EFFECT OF TEMPERATURE ON THE METABOLIC ACTIVITY OF THE STARFISH *ACANTHASTER PLANCI* (L.)

by

Masashi Yamaguchi

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Pacific Science (1974), Vol. 28, No. 2, p. 139-146

ABSTRACT

Standard rate of oxygen uptake in the coral reef asteroid Acanthaster planci (L.) was determined for the temperature range of 25° to 33°C and a metabolic rate-temperature (M-T) curve was drawn. Acanthaster planci is a metabolic conformer. The rate of oxygen uptake increased with increase of temperature to 31°C. The rate decreased at 33°C, which is slightly above the ambient temperature for the laboratory-reared Acanthaster planci tested. The decrease indicates a disturbance in the metabolic activity due to the elevated temperature. The incipient thermal death point for the asteroid was estimated to be near 33°C, at which temperature the animals did not maintain a normal behavior in feeding and resting cycles. Increasing modification in thermal conditions by human activity would pose a hazard to the maintenance of coral reef communities if Acanthaster planci represents metabolic conformer invertebrates with narrow tolerance to elevated temperature.

APPENDIX B

EFFECTS OF TEMPERATURE ON FERTILIZATION AND EARLY CLEAVAGE OF SOME TROPICAL ECHINODERMS WITH EMPHASIS ON *ECHINOMETRA MATHAEI* (DE BLAINVILLE)

by

John H. Rupp

This Paper has been published in:
Marine Biology 23, 1883-189 (1973)

ABSTRACT

Select temperatures, above normal, are shown to reduce success of fertilization and normal early cleavage in the laboratory for the echinoderms *Acanthaster planci* (L.), *Culcita novaeguineae* Muller and Troschel, *Linckia laevigata* (L.), *Echinometra mathaei* (de Blainville), and *Diadema savignyi* Michelin. The data indicate that cleavage is more sensitive to increased temperature than is fertilization. Upper tolerance limits for early cleavage in most of the species examined is near 34.0°C. The early developmental stages of *A. planci* were the most sensitive to elevated temperature, and those of *E. mathaei*, the least sensitive. Further experiments with *E. mathaei* showed that unfertilized ova were still viable, dividing normally when fertilized after 2 h exposure at 36.0°C. The ova were significantly less viable after 3 h. Early cleavage stages of *E. mathaei* were resistant to 36.0°C for exposure times of up to 40 min. but were inhibited beyond this period. It is suggested that the ability of *E. mathaei* to develop normally at 34.0°C (6 C° above ambient temperature) and to withstand limited exposure to 36.0°C may account for the wide distribution of this species in habitats which are often subjected to broad temperature fluctuations, such as reef flats.

APPENDIX C

THERMAL STRESS IN *CAULERPA RACEMOSA* (FORSSK.) J. AG. AS MEASURED BY THE OXYGEN TECHNIQUE

by

Thomas C. Hohman and Roy T. Tsuda

INTRODUCTION

Numerous studies (see Biebl[1]) have been carried out on thermal tolerance in marine algae. The majority of these studies have focused on temperate algal species, and deal with tolerance limits and the optimum temperatures at which these species can survive. While these reports indicate that the majority of species studied are characteristically found growing within a specific temperature range, and rarely survive temperatures outside of this range, little quantitative data have been presented to demonstrate the metabolic changes of algae within this range.

Recently, Yokohama[2] reported on the photosynthesis-temperature relationship in several marine algae from Shimoda, Japan, which has a seasonal seawater temperature fluctuation between 13° and 24°C. He provides quantitative photosynthetic and respiration values for several algal species at various temperature points within their thermal tolerance range. However, the situation on coral reefs is considerably different since the yearly temperature fluctuation is small and the marine algae are already living very close to their upper temperature tolerance in the natural environment (Mayer[3]).

The purpose of this paper is to determine the effects of temperatures within the tolerance range on plant photosynthesis and respiration, and to explore the method of quantifying thermal stress in marine algae by using the net photosynthesis respiration ratio (P/R ratio) as an indicator. At ambient temperature when the light intensity is above saturation level, the P/R ratio is expected to be above 1. Any significant decrease in the P/R ratio at temperatures higher than ambient during the light hours may be interpreted as an indication of metabolic stress. If the P/R ratio is 1, the algae are still capable of surviving. However, if the P/R ratio is less than 1, the algae, although still alive, cannot theoretically survive for any length of time unless heterotrophy is taking place.

MATERIALS AND METHODS

Caulerpa racemosa (Forssk.) J. Ag., a green siphonaceous alga commonly found on reef flats, was chosen as our experimental alga because considerable information has been gathered on its photosynthetic periodicity (Hohman[4]) and its ecological response to different light intensities (Peterson[5]). In addition, this alga is accustomed to periodic exposure at low tides and seems better adapted to tolerate temperature extremes than algae inhabiting the subtidal zone.

In this preliminary study, three experiments were run which differed only in the duration at which the algae were held in their respective temperature baths - experiment 1, 12 hours; experiment 2, 2 hours; and experiment 3, 0 hours.

Specimens of Caulerpa racemosa of comparable size and age were collected from the same field population and taken to the laboratory where all visible epiphytes were removed. Five specimens were held in each of the four separate temperature baths which were supplied with fresh flowing seawater and exposed to natural illumination (ca. 10,00 f.c.). The baths differed only in the temperature of the water - bath 1 (ambient temperatures of 28 to 29°C), bath 2 (ambient plus 2°C), bath 3 (ambient plus 4°C), and bath 4 (ambient plus 6°C).

One hour before incubation, four light bottles and three dark bottles (435 ml capacity) were filled with previously vacuumed filtered seawater of known oxygen concentration and were placed in each bath to be temperature equilibrated. Vacuum filtered seawater at a pressure of 8 mm of mercury decreased oxygen concentration by 20%.

Algae were then placed into three of the light bottles and two of the dark bottles. The remaining two bottles without algae were used as controls. The algae were incubated for 30 minutes at the same time each day, i.e., 1200 to 1230, to negate differences caused by photosynthetic periodicity. Prior experiments (Hohman[4]) with incubation periods of 15, 30, 45, and 60 minutes showed that a 30-minute incubation was sufficient to observe noticeable changes in oxygen concentration without demonstrating a bottle effect.

At the end of the incubation period, the water was siphoned into 300 ml BOD bottles for oxygen determination and measured using the azide modification of the Winkler technique APHA[6]). Replicate titrations were run and differed by less than 0.5%. Rates of net photosynthesis, respiration, and P/R ratios were calculated for the algae in each bath.

At the completion of the experiments, the algae were placed in preweighed containers, stored in a drying oven at 105°C for 24 hours, and weighed to the nearest .001 gram. These values were then used to correct differences in the biomass of each alga; thus, final values for net photosynthesis and respiration are expressed as mg O_2 per gram dry weight per hour.

RESULTS AND DISCUSSION

The results of the three experiments (Fig. 1) agree closely. The highest rate in net photosynthesis in each of the experiments occurs at 28° (ambient). At temperatures above 28°C, the photosynthetic rates decrease continuously in each experiment.

The respiration rates of Caulerpa racemosa demonstrate a sharp increase

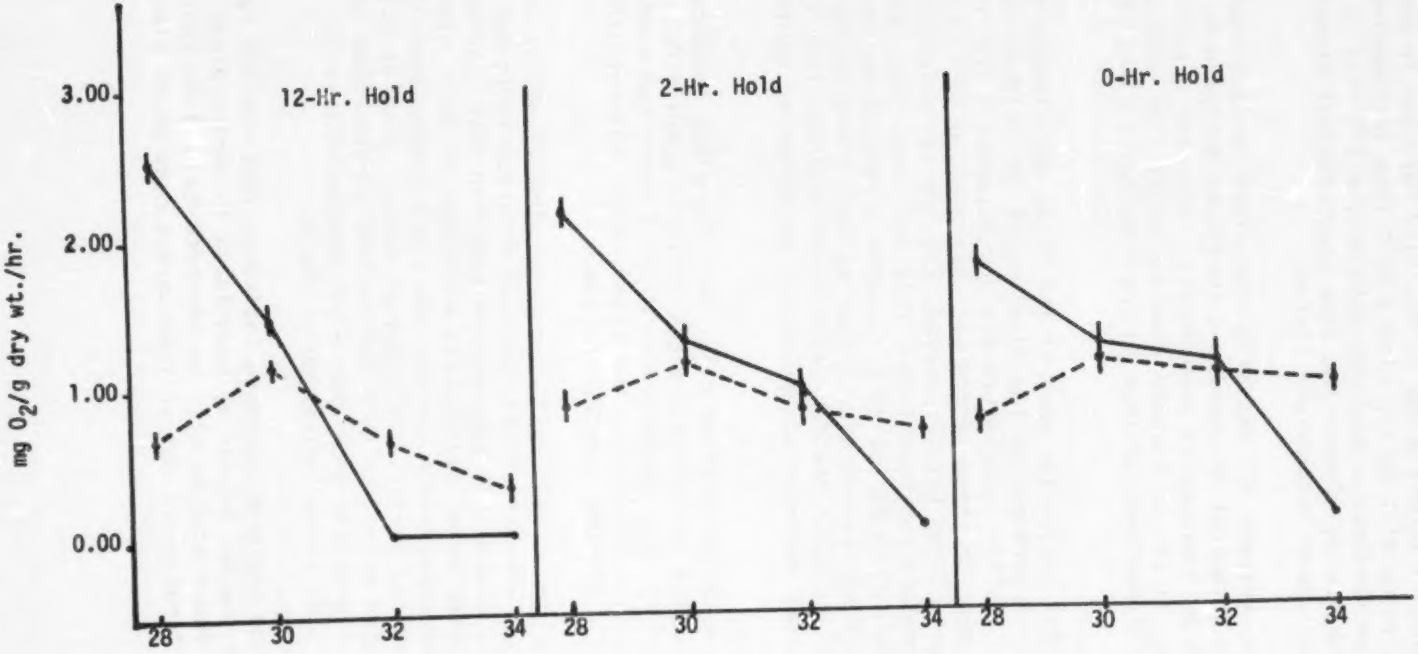

Figure C-1. Net photosynthesis and respiration values.

between 28° and 30°C. This increase was much higher than expected. Most investigators (Giese[7]) report a two to fourfold increase in the respiration rate (Q_{10} value of 2 to 4) with a 10°C rise in temperature. In these experiments we obtained a doubling with only a 2°C rise in temperature. This observation reinforces the idea that tropical organisms do live closer to their upper temperature limits.

At higher temperatures, between 30° and 34°C, the algae in each experiment again demonstrate agreement by showing a continual decrease in respiration rates with an increase in temperature. When the respiration rate begins to decline, it can be assumed that the algae have been exposed to temperatures higher than optimum in the biokinetic zone, thus resulting in injury.

Figure 2 presents the P/R ratios for each of the three experiments at the four temperatures. Regardless of the duration of the holding period, the algae incubated at ambient temperature all demonstrated a P/R ratio much greater than 1. When the temperature was increased to 30°C, again regardless of the length of the holding period, the P/R ratio in each of the experiments decreased to about 1.00. This indicates that the 2°C rise in temperature - from 28° to 30°C - exerts a very large thermal stress on the algae. These results are similar to that cited by Moore[8] in a study by Montfort[9] in which the P/R ratio first rose and then fell when Porphyra, a red alga, was exposed to various temperatures between 5° and 21°C.

In the experimental temperature bath at 32°C, only the algae incubated for short duration were able to maintain a P/R ratio at about 1.00. The algae which were exposed to this temperature for 12.5 hours had a P/R ratio much lower than 1.00. Obviously, the algae cannot tolerate this temperature extreme for prolonged lengths of time.

All of the algae maintained at 34°C exhibited a net photosynthesis of 0.00; thus the P/R ratios are also 0.00. This observation indicates that the algae cannot tolerate this temperature even for short periods of time. The lighter green color and flaccid condition of these algae at the completion of the experiments confirm the above observation. These changes are considered (Biebl[1]) as signs of death. Similar observations were made on algae stored at 32°C for periods greater than two hours. The observations possibly show that a net photosynthesis of 0.00 or a P/R ratio of 0.00 is an indication of death.

This preliminary study on Caulerpa racemosa indicates that the P/R ratio may be used to quantify thermal stress or even death in marine algae. It is anticipated that these studies will be extended to include those blue-green algae which inhabit thermal effluent areas near power plants.

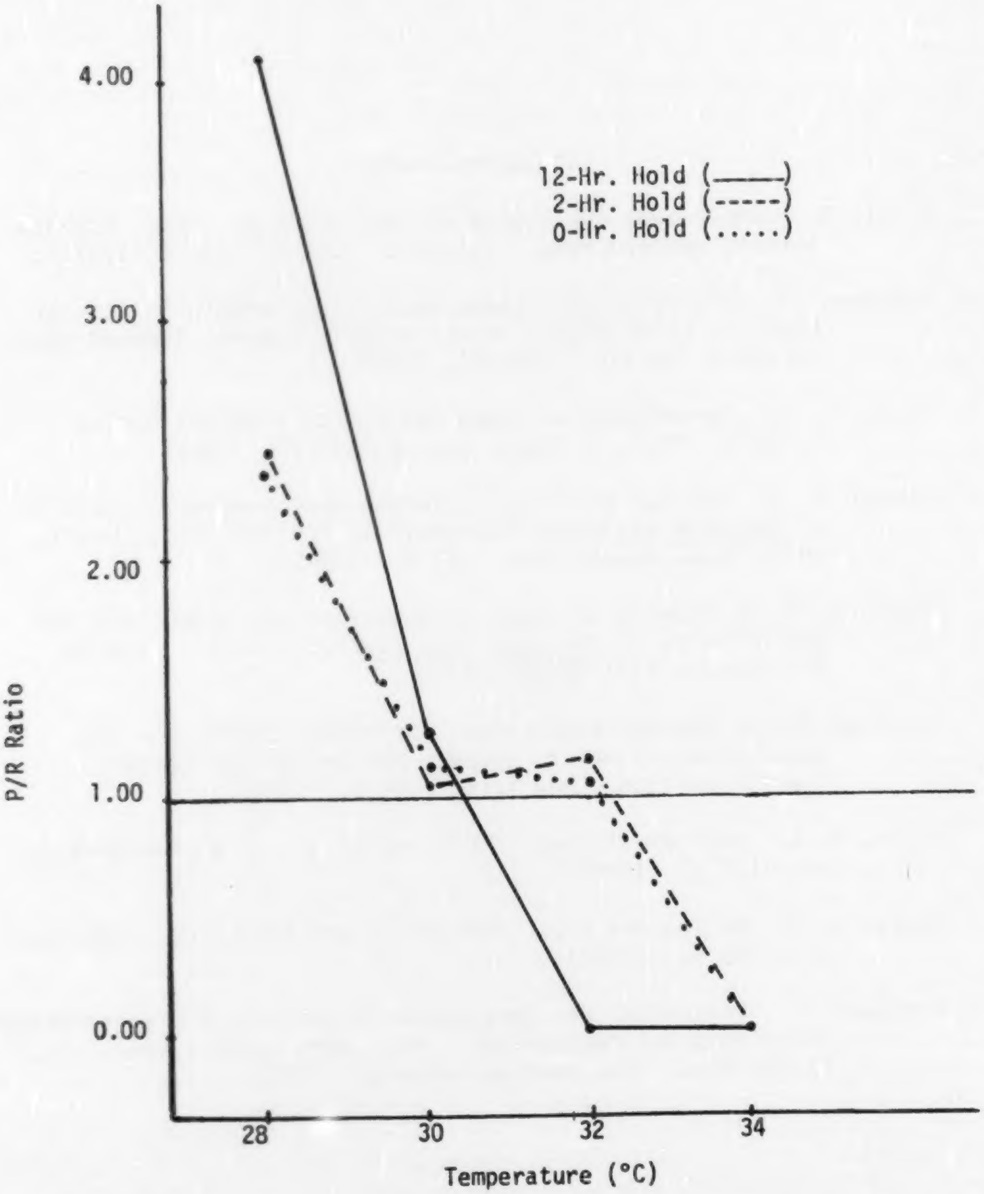

Figure C-2. Net photosynthesis/respiration ratio

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APPENDIX D

EFFECT OF HEATED WATER ON TWO SPECIES OF CRUSTOSE CORALLINE ALGAE, *POROLITHON ONKODES* AND *HYDROLITHON REINBOLDI*

by

Gregory Gordon

INTRODUCTION

Reef corals are often credited entirely with formation of tropical reefs, but the corals share their importance as reef builders with another group of organisms, the crustose coralline algae (Corallinaceae). These algae are important for their contribution in cementing the reef structure. One species, Porolithon onkodes, has long been noted for its key role in this regard. This species is adapted to live on the reef margin where the force of the waves is met and absorbed. Although other corals coralline algae are found here, P. onkodes is usually the dominant organism and imparts to the reef margin its characteristic pink color. Coral reef biologists generally agree (Gardiner, 1903) that without this living layer of calcium carbonate secreting organisms (primarily P. onkodes) on the reef margin, the force of wave attack and subsequent run-off would erode away the reef margin. It is not known how quickly this might occur, but the process would be hastened by the many burrowing organisms that tend to weaken the reef structure. Forms of stress that would remove both corals and coralline algae could lead to this condition.

The heated sea water effluent from Guam's Tanguisson Power Plant is released on the reef flat and flows across it to the reef margin where it begins mixing with oceanic water. It has been noted in the field (Section VIII) that scleractinean corals are killed by this effluent. The purpose of this preliminary study was to observe, experimentally and in the field, the tolerance of Porolithon onkodes and Hydrolithon reinboldi to thermal stress. Hydrolithon reinboldi is a reef flat crustose coralline algae commonly found on Guam reefs.

MATERIALS AND METHODS

The same thermal apparatus described by Jones and Randall (Section IX) for testing corals was used. Temperature increments of +2°C were added so that in each series of three tanks the temperature would be 28 (control), 30, 32, and 34°C.

Specimens of Porolithon onkodes were collected by breaking off pieces from the reef margin with hammer and chisel. Hydrolithon reinboldi commonly encrusts entire rocks on the reef flat and these rocks were gathered. Specimens tested were held in the Marine Laboratory running seawater system for at least two weeks prior to being used in the thermal experiment. H. reinboldi showed little obvious sign of stress as a result of this, but nearly half of the P. onkodes specimens died during this acclimation period. Other P. onkodes specimens experienced death of some of the cells around the edges of the specimen. Perhaps this was a result of the damage caused by collecting them, or it may reflect the sensitivity of P. onkodes to stresses inherent in the seawater system itself. Survivors eventually stabilized.

To reduce the initial shock of the heated water, specimens were placed in buckets of ambient temperature seawater. The buckets were placed in the tanks and the specimens allowed to slowly acclimate to the tank temperatures. When the water temperature of the buckets equaled that of the tanks, the specimens were placed in the tanks (about three hours).

Determining the death point of an alga is difficult. The most accurate methods measure changes in the plant's physiology such as their rate of photosynthesis versus their rate of respiration and noting when this P/R ratio drops (see Appendix C). Because of time limitations, the method used here had to be a subjective visual observations. The thalli of the specimens were observed for loss of color. White was considered dead, although other color changes were noted and experience eventually proved that these color changes were merely early indications of death. A thallus becomes completely white only after cell pigments have diffused out or decomposed. Death undoubtedly precedes this final step of decomposition with at least 24 hours seeming to be a conservative minimum.

A complication in the study occurred because the specimens do not respond as one organism. Death of the thallus often is by degrees, with some cells turning white (dying) while others remain a healthy color (alive). This slow destruction was followed and recorded as the percent of the thallus appearing white versus the percent remaining healthy. The percentages were determined visually and recorded in increments of 5%. I was confident that the observations were in error by no more than ±5%. In some cases it was necessary to use specimens that had already experienced partial damage while in the holding tanks. Die off occurred early and the thalli eventually stabilized. To simplify determination of the amount of change occurring, the entire original thallus was given a percent dead versus a percent alive ratio. To use the initial percent alive values from these specimens, the values were multiplied by a conversion factor determined from the original percent dead:percent alive ratio. This corrected the percent alive number to one that indicated the percent that remained alive from the 100% that started out the experiment alive. (For example, if 80% of the original thallus was alive, then 80 divided into 100 gives a conversion factor of 1.25. The conversion factor was multiplied by all subsequent percent alive values. An experimental percent alive value of 60% would be corrected to 75%).

It was then possible to sum the percent alive values of the six specimens from each temperature series to obtain a mean number of the percent of algae remaining alive after each day. The daily mean values have been plotted on graphs showing the results from the four temperature series. On days when the specimens were not checked, the days have been left blank in the graphs, and dotted lines used to connect the plots for the mean values of each series. *H. reinboldi* was tested for 14 days and *P. onkodes* for 28 days.

Field observations were made in an effort to correlate the experimental work with the situation as it now exists on the reef flat affected by the Tanguisson Power Plant effluent water. Subjective observations were made at low tide on the reef flat and reef margin in the area in front of and south of the power plant where the hot water effluent impinges on the reef. Observations were also made in the surge channels in front of the effluent area to observe possible effects along the sides and bottom of these channels.

RESULTS AND DISCUSSIONS

The results of the experiments are presented in Figures 1 and 2.

Figure 1 shows that *Porolithon onkodes* in the 32° and 34°C tanks exhibits signs of stress after one day. At the end of six days, all the algae in these two temperature series were dead. This is in marked contrast to the results for *Hydrolithon reinboldi*, Figure 2. This reef flat algae seems to tolerate for five days the stress of the 34°C water. It then began to die slowly in the 34°C tanks, and all would have probably died if the experiment had run for a longer period of time. In the 32°C temperature series, 90% of the thalli of *H. reinboldi* remained alive after 14 days.

In the 28°C (ambient) and 30°C tanks, the *P. onkodes* showed signs of stress after 14 days that was not exhibited by *H. reinboldi*. *H. reinboldi*, after 14 days, had mean values of 98 and 99 percent of its thalli remaining alive in the 28° and 30°C tanks respectively. *P. onkodes* had mean values of 82 and 50 percent in the 28° and 30°C tanks respectively. After 28 days *P. onkodes* had mean values of 51 and 24 percent from the 28° and 30°C tanks respectively. This may indicate that with time, slow attrition of *P. onkodes* occurs, even in ambient seawater. This makes it more difficult to assess the effects of the 30°C seawater on *P. onkodes*, but does indicate the sensitivity of the species to stress. Since the percent alive values are consistently lower in the 30°C tanks, it still appears reasonable to assume that the temperatures of +2°C above ambient stressed the *P. onkodes* enough to cause some death.

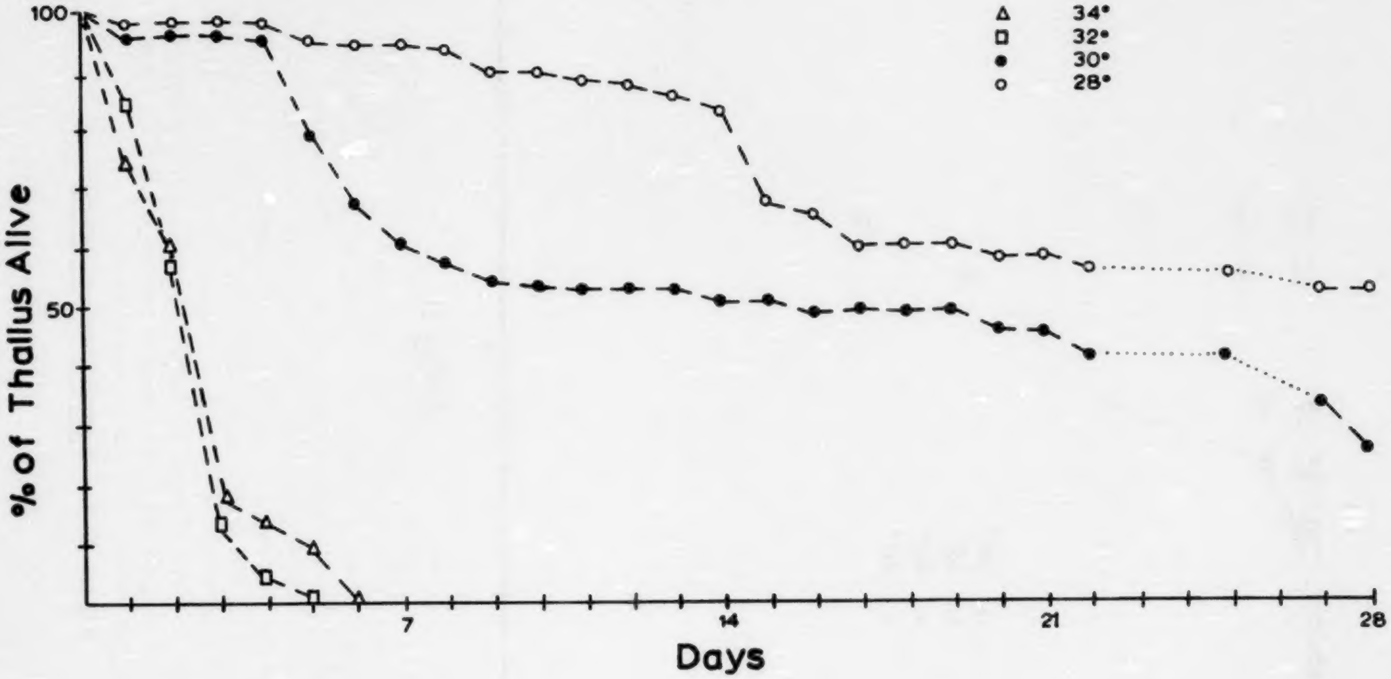

Figure D-1. *Porolithon onkodes.*

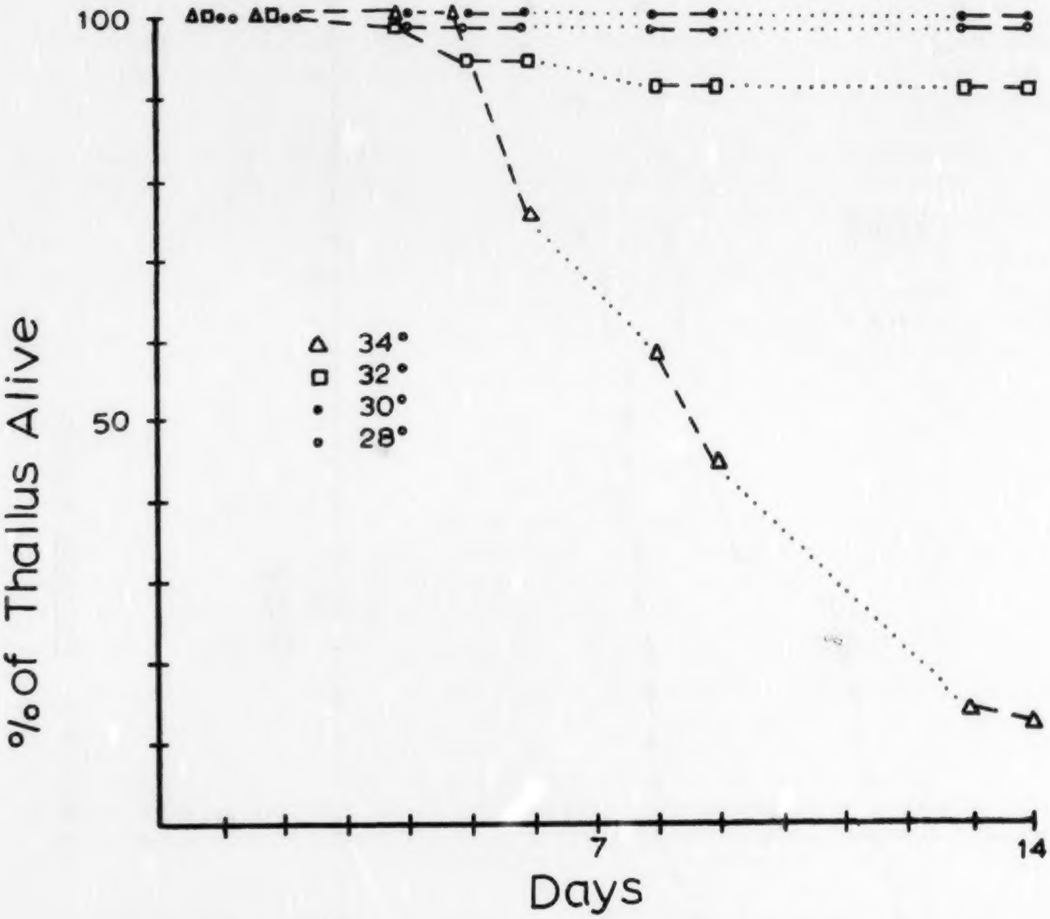

Figure D-2. Hydrolithon reinboldii.

The experimental results indicate that the reef flat coralline algae *H. reinboldi* is adapted to withstand the effects of higher than ambient water temperatures better than *P. onkodes*. This would be expected since reef flat algae are normally subjected to higher than ambient oceanic water temperatures during the daytime low tides of summer. *P. onkodes* grows on the reef margin where it is continually washed by seawater at ambient temperature. Thus adaptation to water temperatures much higher than ambient would not be expected.

The experimental design does not emulate the thermal stress normally experienced on the reef flat where the alternating high and low tides result in a cycle including periods of thermal stress followed by periods of immersion in ambient seawater. This is in contrast to the continual immersion in heated water that occurred in the experiment and opposite the power plant.

Coralline algae usually grow outward from a central area, often overlapping itself or other organisms. On the reef margin, individuals of *P. onkodes* are continually overlapping each other so that any specimen collected is likely to be composed of more than one individual. A result of these patterns of growth is that in any type of specimen collected, cells of that specimen are likely to be of differing stages of growth and development. This may partially explain why some of the thalli died and the remainder stayed alive in a given specimen. The cells comprising it were in varying stages of senescence, and as a result some were weaker than others. Stresses that normally would have been tolerated, instead led directly or indirectly to their death.

Section VI of the primary report reported temperatures in the effluent at a low tide as follows: the stilling well was 33.4°C, mid-reef flat was 33.4°C, water cascading into the surge channels was 33.2°C, and at the midpoint of the reef margin width was 32 to 32.8°C. The reef flat temperatures approximate the temperatures in the 34°C temperature series. Along the reef margin the temperatures would roughly correspond to the 32°C temperature series.

Utilizing temperature data from the field and the experimental results, it would be logical to predict that no *H. reinboldi* would be found on the reef flat in the stream of the heated effluent water, and that along the reef margin in this area the *P. onkodes* would be dead. This is essentially the situation that was found to exist when field observations were made on the reef flat and reef margin at the Tanguisson Power Plant site.

The reef flat in the area covered by the effluent contains a great deal of rock and rubble of the type commonly found encrusted by *H. reinboldi* on normal reef flats. The turbulence of this water would seemingly make it an even more suitable habitat under conditions of ambient seawater temperatures. Observations of this area revealed very little crustose coralline algae of any type. Some *H. reinboldi* was seen, but it was always growing in small depressions, where perhaps the effluent would tend to flow over the top and not impinge directly on the algae. Occasional waves do wash into this area, bringing with them cooler water. This cooler water, being denser, may settle into the depressions, thus insulating the algae. In no case was there extensive growth of coralline algae in this area. Both north and south of this intake channel, where there is little or no impingement of hot water effluent, *H. reinboldi* was again found.

In dealing with *P. onkodes* along the reef margin,the following condition was noted. Daytime low tides begin in May and impose a seasonal stress on the reef flats of Guam. This is frequently noticable along the raised algal ridge in back of the reef margin where the *P. onkodes* is often exposed, and if it becomes dessicated, will die. Weak surf conditions are common in the summer, and so this die off commonly happens. Littler (1973) described this phenomenon in Hawaii and indicates that with the resumption of heavy surf and daytime high tides, *P. onkodes* quickly recolonizes the area. I inspected the Tanguisson reef platform in mid-July and by this time one could see that these seasonal stresses had resulted in some natural death along the reef margin. It was not possible to separate this from death due to the hot water effluent. To deal with the situation, I considered partial death along the reef margin as normal and made what I consider to be conservative estimates of the effects of the hot water effluent on the reef margin.

Damage to the reef margin has been heavy in front of the plant outfall and south for a distance of approximately 100 m. No *P. onkodes* is found growing on top of the reef spurs except at their extreme seaward point where the spurs are below water at all times. Along the sides and bottom of the spurs there was no *P. onkodes*. The only algae seen were in holes and crevices in the substrate where they would be protected from direct impingment of the heated water. In this region, nearly all the *P. onkodes* has been killed, and filamentous blue-green algae now predominate in the area.

In that area 100-200 m south of the Tanguisson Power Plant, the *P. onkodes* along the reef margin has received at least moderate damage from the heated water effluent. This is primarily evident on top of the spurs of the reef margin. The surge channels and sides of the spurs were not checked, but since the heated water does not run directly into the spurs at this point, plant influence is probably confined to the surface layer of water, and thus only the top of the reef margin is likely to be affected.

Beyond 200 m the amount of damage gradually diminishes, but it was impossible for me to estimate at what point there was no further death resulting from the power plant.

CONCLUSIONS

1. *Porolithon onkodes* growing along the reef margin is less tolerant of the stresses resulting from hot water effluent than is the reef flat species, *Hydrolithon reinboldi*.

2. Almost all the *H. reinboldi* formerly growing in the area where the heated effluent water from Tanguisson Power Plant now flows across the reef is now dead.

3. Significant damage has occurred to the groove and spur system of the reef margin directly in front of the Tanguisson Power Plant where the heated effluent water is discharged. This damage is caused by the heated water killing the *P. onkodes* normally found living there. Reef margin damage extends south of the power plant for at least 200 m, with the amount of damage gradually diminishing the further south one goes.

4. Death of the *P. onkodes* along the first 100 m of reef margin has probably made that area more susceptible to erosional effects of breaking waves and water.

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1-	10/6/70	Flood to ebb
2-	10/9/70	Flood
3-	12/23/70	Flood to ebb
4-	23/23/71	Ebb to flood
5-	3/4/71	Flood to ebb
6-	3/17/71	Ebb
7-	3/24/71	Ebb to flood
8-	3/31/71	Ebb
9-	4/18/71	Flood to ebb
10-	4/29/71	Flood to ebb
11-	5/6/71	Ebb
12-	5/11/71	Ebb
13-	6/9/71	Ebb
14-	6/17/71	Flood (weak)
15-	6/23/71	Ebb
16-	7/1/71	Flood (weak)
17-	7/9/71	Ebb
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